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The Journal of
THE ROYAL AERONAUTICAL SOCIETY

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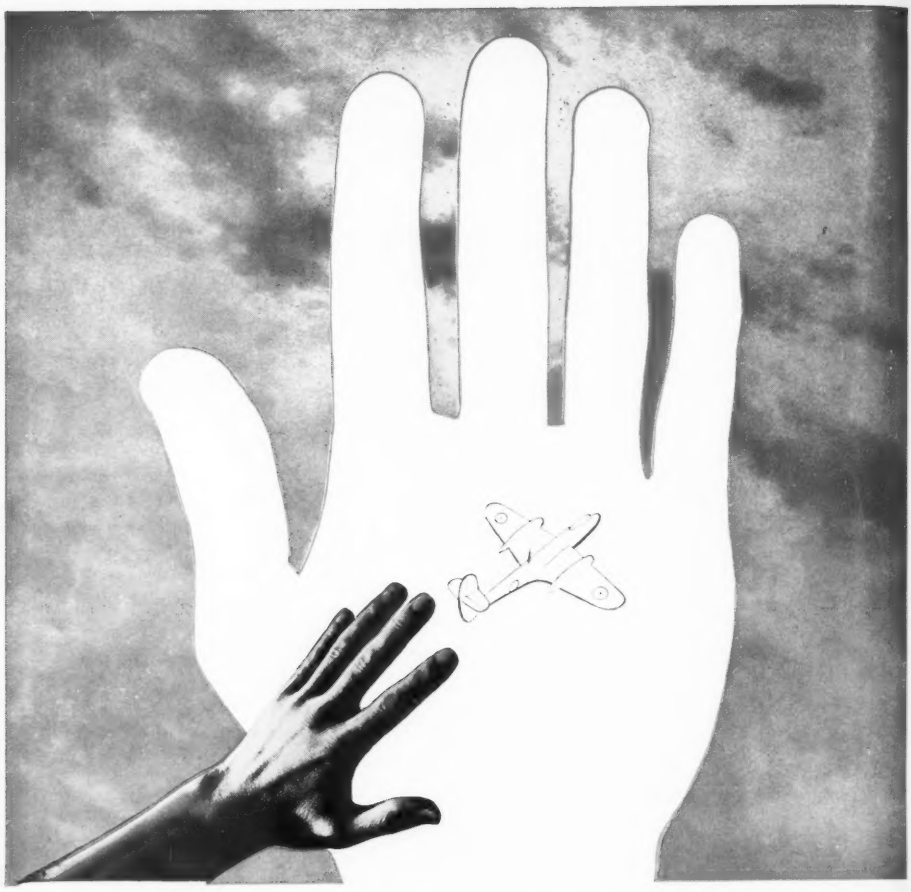
1950 GARDEN PARTY

REVIEWS CORRESPONDENCE

LONDON
ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, W.1



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JUL 25 '50

THE ROYAL AERONAUTICAL SOCIETY

GRADUATES' AND STUDENTS' SECTION

July 1950

AERONAUTICAL TRAINING FACILITIES IN THE E. YORKS AREA

Facilities for aeronautical training in the East Yorkshire area are founded upon close co-operation between Blackburn and General Aircraft Ltd. and Kingston-upon-Hull Technical College. Thus it is possible to achieve an adequate balance between the practical and theoretical training of the students and apprentices. Lack of adequate representation of industry at the technical colleges has often led to theoretical instruction lagging behind technical developments but this scheme offers a neat and essentially practical solution to such shortcomings.

APPRENTICESHIP AT BLACKBURN AIRCRAFT LTD.

The grades of apprenticeship available are as follows:—

Division I General Aircraft Engineer Apprentice
Division II Student Apprentice
Division III Trade Apprentice

with additional upgraded classes:—

Division IIIa Drawing Office Apprentice
Division IIIb Production Engineer Apprentice

The general aircraft engineering apprentice is intended to become a fully qualified aeronautical engineer and to obtain the appropriate professional qualifications. The first two years of the apprenticeship are devoted to working in the various departments, the time allotted depending upon the importance of the shop. During this time he attends evening classes at Hull Technical College for which part-time day release facilities are available, and on completion of this period he should obtain the Ordinary National Certificate. It is then intended that he shall enter upon a two and a half years' full-time day course for the Higher National Diploma at the same college as later described. Finally for the last six months the apprentice returns to the factory and continues training in one of the technical offices for which there are appropriate training sections in each office.

The student apprentice is either a university graduate or one drawn from ex-Service personnel having a measure of practical experience in the engineering branch of his Service. The course is nominally of two years' duration providing practical workshop training which may be implemented, if so desired, by specialised theoretical training appropriate to the technical offices.

Trade apprenticeships exist to produce skilled craftsmen after a five years' practical course but provided adequate theoretical study is undertaken, the apprentice may be upgraded to either a drawing office apprentice or production engineering apprentice with the facilities of the general aircraft engineer apprentice. He thus eventually gains his Higher National Certificate either in aeronautical subjects or production engineering.

MUNICIPAL TECHNICAL COLLEGE, PARK STREET, KINGSTON-UPON-HULL
SCHOOL OF AERONAUTICAL ENGINEERING

The Aeronautical Courses at this College are divided into two parts as follows:—

1 Full-Time Day Courses.

(*a*) Higher National Diploma in Aeronautical Engineering. This is normally a three year course and covers a comprehensive range of subjects carefully selected to give the students a thorough grounding in all branches of airframe design.

Conditions of entry:—

(*i*) Minimum age on entry 18 years.

(*ii*) Students without previous technical training should be able to produce evidence of an educational standard approximating to Higher School Certificate.

(*iii*) Students holding the Ordinary National Certificate (with special aeronautical subjects and two years works experience) are exempt from the subjects of Physics, Geometrical and Engineering Drawing and Workship Technology of the first year, and will be permitted to complete the course in 2½ years.

(*iv*) Students holding the Ordinary National Diploma in Mechanical Engineering are exempt from the whole of the first year.

Subjects of the Course:—

The subjects taken comprise—Pure and Applied Mathematics, Physics, Chemistry and Metallurgy, Applied Mechanics, Geometrical and Engineering Drawing, Workshop Technology, Strength of Materials, Theory of Structures, Aero Design, Aerodynamics and Mechanics of Fluids, Heat Engines and Theory of Machines. Laboratory practice is allied with the appropriate subjects.

Exemptions.

Holders of the Diploma are exempt from Sections A and B of the Associate Membership Examination of the Institution of Mechanical Engineers and from Part 1 of the Associate Fellowship Examination of the Royal Aeronautical Society.

London B.Sc.

(*b*) The School of Aeronautical Engineering is recognised for the preparation of students for the London B.Sc. subjects of Mechanics of Fluids and Theory of Structures. Qualified students may thus take the London B.Sc. in Mechanics of Fluids (Aerodynamics), Theory of Structures (Aircraft Structures), Strength of Materials and either Mathematics of Applied Thermodynamics or Theory of Machines, or suitable variations of these.

2 *Evening Class or Part-Time Courses.*

An organised course of study is provided for:—

(*a*) The Ordinary National Certificate in the subjects of Mathematics, Applied Mechanics and Aeronautics.

(*b*) The Higher National Certificate in the subjects of Mathematics, Theory of Structures and Aerodynamics, Strength of Materials and Theory of Machines. Lectures are given three evenings a week or on suitable substituted half days between September and April inclusive. Laboratory training is included in Aerodynamics, Strength of Materials and Theory of Machines.

Exemptions.

Holders of the Higher National Certificate with Aeronautical Subjects are exempt from Sections A and B of the Associate Membership Examination of the Institution of Mechanical Engineers and from Part 1 of the Associate Fellowship Examination of the Royal Aeronautical Society on a subject for subject basis.

Accommodation and Equipment.

The School of Aeronautical Engineering is housed in a separate building in Middleton Street, Hull, and comprises two Aerodynamics Laboratories, a Structures Laboratory and a Drawing Office, together with suitable Lecture Rooms.

The Aerodynamics Laboratory equipment includes one 4 ft. square, closed jet, straight through flow N.P.L. type tunnel, one closed jet return flow tunnel, working section 2 ft. 6 in. by 1 ft. 6 in., a 3 ft. square visual panel smoke tunnel, and a large selection of models for testing and demonstration.

The Structures Laboratory equipment includes a 7 ft. strut testing machine, maximum load 7 tons. A rig for testing thin webbed beams, ribs, etc., strain gauge equipment and a selection of statically determinate and indeterminate structural models.

The Strength of Materials, Theory of Machines, Heat Engines and Physics Laboratories are situated at Park Street, together with the Engineering Workshops. There is a small workshop in the Middleton Street building for the maintenance and improvement of the specialised apparatus.

JUL 25 '50

THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES JULY 1950

AUGUST BANK HOLIDAY

The library and offices of the Society will be closed from 5 p.m. on Friday 4th August until 9 a.m. on Tuesday 8th August 1950.

SECRETARYSHIP OF THE SOCIETY

The Secretaryship of the Royal Aeronautical Society will become vacant on the approaching retirement of Captain J. Laurence Pritchard, and the Council now invite applications for the post.

The Secretary is the executive officer of the Society, responsible to the Council for implementing the policy of the Society and managing its affairs. He is head of the permanent staff and it is his responsibility to maintain close relationship with other engineering and scientific institutions and societies, official organisations and the like, and the Society's Divisions and Branches Overseas. The Secretary is also responsible for organising the Society's social functions.

Preference will be given to candidates with an aeronautical background who have had administrative experience. The salary will be in the range of £1,250 to £1,500 depending upon qualifications. The post is pensionable at 65.

Applications should be addressed to The Secretary, 4 Hamilton Place, London, W.1 before 31st July 1950.

CONTENTS OF THE JULY JOURNAL

The 38th Wilbur Wright Memorial Lecture—Some Aspects of Expenditure on Aviation, Sir Richard Fairey, M.B.E., Hon.F.R.Ae.S.

Flight Refuelling and the Problem of Range, C. H. Latimer-Needham, M.Sc., F.R.Ae.S., M.S.A.E.

Elementary Aspects of Technical Statistics and Common Fallacies—With Examples of Measurement of Aero Engine Reliability, W. E. Thornton-Bryar, B.Sc.(Econ.), A.I.S., F.S.S., A.R.Ae.S.

1950 Garden Party.

Reviews.

Correspondence.

THE AERONAUTICAL QUARTERLY—Volume II

Part I, Volume II, of "The Aeronautical Quarterly" is still available from the offices of the Society at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members, post paid.

The contents are:—

Two-Dimensional Theory of Stiffened Plates	Chang O'Chou
The Whirling of a Spinning Top	J. Morris
The Possibility of the Determination of Rate of Climb from Acceleration Measurements in Level Flight ...	E. C. Pike
A Note on Subsonic Aerofoil Theory	John W. Miles
Theory of an Oscillating Supersonic Aerofoil	Geoffrey L. Sewell
The Linearised Theory of Conical Fields in Supersonic Flow, with Applications to Plane Aerofoils	S. Goldstein and G. N. Ward

Volume I of "The Aeronautical Quarterly" (copies of which are still available) has been well received both in Great Britain and overseas; the response has been encouraging and reviews published both in this country and the United States have praised and welcomed both the appearance and contents of the Society's new publication. As the circulation increases more papers will be published in each part.

The special attention of members is drawn to the fact that a strictly limited edition only of "The Aeronautical Quarterly" is printed and numbers cannot be reprinted in any circumstances. An annual subscription is therefore advisable.

BIRTHDAY HONOURS

The President and Council congratulate the following members whose names were included in the Birthday Honours List:—

Baron—E. W. Hives, *Fellow*.
K.C.G.B.—Air Chief Marshal Sir Ralph Cochrane, *Associate Fellow*.
K.C.B.—Sir Ben Lockspeiser, *Fellow*.
C.B.E.—F. T. Hearle, *Fellow*, Captain J. Laurence Pritchard, *Honorary Fellow*, T. Rowntree, *Fellow*.
O.B.E.—H. P. Folland, *Fellow*.

ASSOCIATE FELLOWSHIP EXAMINATIONS

The Special Examination under the Old Syllabus will be held on 29th, 30th and 31st August 1950. All those candidates who have entered will be sent full particulars and time-table direct, but note should be made of the dates.

Home entries for the December Examination under the new Syllabus should be received by the Secretary not later than the 31st August 1950. The lists for entries outside the United Kingdom have been closed.

POSTS AT THE ROYAL AIRCRAFT ESTABLISHMENT

Senior Experimental Officers (Structures Department)

The Ministry of Supply invites applications from Mechanical and Aeronautical Engineers for unestablished appointments in the grade of Senior Experimental Officer in the following fields of work in the Royal Aircraft Establishment (Structures Department), Farnborough, Hants.

Post 1. *Fatigue of Aircraft Structures.* Experience in theory and practice of structural testing of aircraft is required and a knowledge of the fatigue characteristics of metals is desirable.

Post 2. *Strain Gauge Installations on Aircraft.* Calling for electronic experience with ability to adapt instruments for use in this connection on the ground and in flight.

Post 3. *Aircraft Accident Investigations.* Practical airframe experience is essential and experience in an aircraft design office is desirable.

Post 4. *Static Aero-elastic, Flutter and Vibration Problems of Aircraft.* Experience of design and experimental research work on aircraft is required.

Candidates should be not less than 35 years of age and as a minimum must have a Higher National Certificate or equivalent qualification. An engineering apprenticeship is desirable. Salary according to age and experience within the range £705-£895 (men); £580-£790 (women).

Write, quoting C 300/50A and Post No. to Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, London, W.C.2, for application forms, which must be returned completed by *31st July 1950.*

Experimental Officers (Aerodynamics Department)

The Ministry of Supply invites applications from Mechanical and Aeronautical Engineers for unestablished appointments in the Experimental Officer Class at

the Royal Aircraft Establishment (Aerodynamics Dept.), Farnborough, Hants, for work in Flight Research, Supersonic and Subsonic Wind Tunnels, and in the Seaplane tank.

Minimum qualification is the Higher National Certificate or equivalent qualification and an engineering apprenticeship would be an advantage. Candidates should have a capacity for experimental work and for posts graded Experimental Officer experience in such work is essential. Salary according to age and experience within the ranges:—

Experimental Officer (minimum age normally 28), £495-£645; Assistant Experimental Officer, £220-£460. Rates for women are somewhat lower.

Application forms are obtainable from Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, W.C.2, and must be returned completed, quoting Reference No. C 301/50A, by *31st July 1950.*

EXPERIMENTAL OFFICERS (Structures Department)

The Ministry of Supply invites applications from Mechanical or Aeronautical Engineers for unestablished appointments in the grade of Experimental Officer at the Royal Aircraft Establishment (Structures Dept.), Farnborough, Hants, in one of the following fields of work:—

C 312/50A (*a*) *Operational Research on Aircraft Flight Load Conditions.* Experience in statistical analysis of data obtained from operational research is required. Experience of aircraft operation conditions is desirable.

(*b*) (*i*) *Loading Conditions for Aircraft Structures.*

(*ii*) *Detail Stress Analysis.*
Knowledge of aerodynamics desirable.

(*c*) *Research and Development and Acceptance Testing of Aircraft Propellers.*

Ref. A173/50A *Development of Strain Measuring Technique.*
Knowledge of photo-elastic and brittle laquer methods desirable.

Candidates should be at least 28 years of age and have experience of the work detailed. Minimum qualification, Higher National Certificate or equivalent. Salary within E.O. range £495-£645 (men); £405-£520 (women).

Write for application form, obtainable from Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, W.C.2, quoting the appropriate reference No. Completed application forms must be returned by *31st July 1950.*

PRINCIPAL SCIENTIFIC OFFICER

The Ministry of Supply invites applications for an unestablished appointment as Principal Scientific Officer in London Headquarters, for supervision of all aspects of research and development in Helicopters, from project stage to completion of tests on experimental types. Candidates must be over 31 years of age and have good honours degree in mechanical or aeronautical engineering or equivalent qualification, with experience in aeronautics. Salary according to age and experience within the range £950-£1,250. Rates for women are somewhat lower. The post carries F.S.S.U. benefits.

Application forms are obtainable from Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, W.C.2, quoting Ref. No. C 290/50A; they must be returned completed by *31st July 1950.*

LAPEL BADGES

Lapel badges are still available to members at 3s. 6d. each, including postage. These badges are gilt enamel with a screw back and are $\frac{3}{4}$ inch in diameter. Remittances should be sent, with applications, to the Secretary at the Offices of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

The prices of binding of Journals are as follows:—

1949 Volume (including packing and postage), 15s. 6d.

Previous Volumes (including packing and postage), 17s. 0d.

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Cases only for unbound 1949 Volumes are available, price 6s. 6d. each. Requests for cases, with remittances, should be sent to the Secretary at the offices of the Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Alan Richard Buley (from Graduate), Alexander John Chivers (from Student), Lindsay Grahame Dawson, Robert Reginald Dexter, Shirley Donald Dickins (from Associate), Alan Victor Garrett (from Graduate); Terence Hilary Weller Gibbons, Frank Robinson Heath, Harold Hodkinson, Albert George Hurn, Frederick John Kemp, Arthur Charles Leftley (from Graduate), John Magson (from Graduate), Raymond Baird Maloy, S. Krishnaswami Rao, Frederick Victor Rehill (from Associate), Ralph Darkin Williams (from Graduate), William Henry Wittrick, Frank Sutcliffe Wood.

Associates

Adolf Frederick William Andren, Alfred James Barnard, Johanan Barsela, Alfred William Charles Cherritt, Victor Harold Davey, Andrew Graham Gerrand, Albert Henry Hall, Sidney Rufus Nicholson, Samuel David Thomas (from Student).

Graduates

Philip Bruce Atkins (from Student), Alan Avery Blythe (from Student), Geoffrey Percival Dollimore (from Student), David Bruce Elkman, John Cecil Martin (from Student), John Leslie Milne, Frank David Moore, Eric Phillip Potter, Francis George Walker, Henry Robert Warren, Muhammad Akbar Yusuf.

Students

Victor Stanley Chambers, Reginald Mark Diamond, Derek Lionel Augustus Hand, Khurshed Rustomji Khory, Soli Kaikhushru Sahiar, Peter Heron Winter, Paul Irving Woodruff.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from: P. Saunders, Esq., *Associate Fellow*, Miss A. D. Betts, *Companion*, and Wing Commander D. M. Egan, *Associate*.

ADDITIONS TO THE LIBRARY

The following have been added to the Library (titles of pamphlets are printed in italics and books marked * or ** may not be taken out on loan):—

Cornell Aeronautical Laboratories	$8\frac{1}{2}' \times 12'$ Variable Density Wind Tunnel. Cornell Aeronautical Laboratory. 1949.
Garner, T. L. and Powell, J. F.	Rubber in Aircraft. British Rubber Development Board. 1950.
Gillett, H. W.	Impact Resistance and Tensile Properties of Metals at Sub-Atmospheric Temperatures. American Society for Testing Materials. 1941.
Miles, E. R. C.	Supersonic Aerodynamics. A Theoretical Introduction. McGraw-Hill Book Co. 1950.
Nayler, J. L.	Modern Aircraft Design. Temple Press. 1950.
Stepniewski, W. Z.	Introduction to Helicopter Aerodynamics. Vol. I. Performance. Rotorcraft Publishing Committee, Morton, Pa. 1950.
Taylor, F. S.	British Inventions. Longmans Green. 1950.
U.S. National Bureau of Standards	Bibliography of Books and Published Reports on Gas Turbines, Jet Propulsion, and Rocket Power Plants. U.S. Government Printing Office. 1949.
Wigdortchik, L. S.	Some Economics of the Helicopter—Present and Future. Helicopter Association of Great Britain. 1949.
*Wilkinson, P. H.	Aircraft Engines of the World. 1950. Paul Wilkinson. 1950.
Zahm, A. F.	Aeronautical Papers. Volume II. University of Notre Dame. 1950.

N.A.C.A. Technical Notes

1766—*Wind-tunnel investigation of effects of tail length on the longitudinal and lateral stability characteristics of a single-propeller airplane model. H. S. Johnson.*

1849—*Use of characteristic surfaces for unsymmetrical supersonic flow problems. W. E. Moeckel.*

2024—*Sound measurements for five shrouded propellers at static conditions. H. H. Hubbard.*

2040—*Analysis of an induction blowdown supersonic tunnel. J. M. Bidwell.*

2044—*Pressure distribution and some effects of viscosity on slender inclined bodies of revolution. M. J. Allen.*

2046—*A method of calibrating airspeed installations on airplanes at transonic and supersonic speeds by use of temperature measurements. J. A. Zalovick.*

2052—*Effects of an aging treatment on life of small cast Vitallium gas-turbine blades. C. A. Hoffman and C. Yaker.*

2053—*Effect of heat and power extraction on turbojet-engine performance, I—Analytical method of performance evaluation with compressor-outlet air bleed. R. V. Hensley, F. E. Rom and S. L. Koutz.*

2054—*Stress and distortion measurements in a 45 degree swept box beam subjected to antisymmetrical bending and torsion. G. W. Zender and R. R. Heldenfels.*

2055—*Tables of wing-aileron coefficients of oscillating air forces for two-dimensional supersonic flow. V. Huckel and B. J. Durling.*

2056—*Velocity distribution on wing sections of arbitrary shape in compressible potential flow. III—Circulatory flows obeying the simplified density-speed relation. L. Bers.*

2059—*Method of experimentally determining radial distributions of velocity through axial-flow compressor. B. H. Finger.*

2060—*A recurrence matrix solution for the dynamic response of aircraft in gusts. J. C. Houbolt.*

2061—*The effect of rate of change of angle of attack on the maximum lift of a small model. P. W. Harper and R. E. Flanigan.*

2062—*Dynamic similitude between a model and a full-scale body for model investigation at full-scale Mach number. A. I. Neihouse and P. W. Pepoon.*

2063—*A comparison of theoretical and experimental wing bending moments during seaplane landings. K. F. Merten, L. J. Redriguez and E. B. Beck.*

2064—*Effect of aspect ratio on the air forces and moments of harmonically oscillating thin rectangular wings in supersonic potential flow. C. E. Watkins.*

2065—*A transformation theory of the partial differential equations of gas dynamics. C. Loewner.*

2067—*Chart for simplifying calculations of pressure drop of a high-speed compressible fluid under simultaneous action of friction and heat transfer—application to combustion-chamber cooling-passages. M. Sibulkin and W. K. Koffel.*

2068—*Theoretical effect of inlet hub-tip-radius ratio and design specific mass flow on design performance of axial-flow compressors. Chung-Hua Wu, J. T. Sinnette, Jnr., and R. E. Forrette.*

2069—*Cylinder-head temperatures and coolant heat rejection of a multicylinder liquid-cooled engine of 1,650-cubic-inch displacement. J. H. Povolny, L. J. Bogdan and L. J. Chelko.*

2071—*Charts of thermodynamic properties of air and combustion products from 300 degrees to 3,500 degrees R. R. E. English and W. W. Wachtl.*

2072—*An investigation of aircraft heaters. XXXIII—Experimental determination of thermal and hydrodynamical behaviour of air flowing along finned plates. L. M. K. Boelter, R. Leasure, F. E. Romie, V. D. Sanders, W. R. Elswick and G. Young.*

2074—*Aerodynamic characteristics at Reynolds numbers of* 3.0×10^6 *and* 6.0×10^6 *of three airfoil sections formed by cutting off various amounts from the rear portion of the NACA* 0012 *airfoil section. H. A. Smith and R. F. Schaefer.*

2075—*Free-flight-tunnel investigation of dynamic longitudinal stability as influenced by the static stability measured in wind-tunnel force tests under conditions of constant thrust and constant power. R. O. Schade.*

2076—*Friction of surface films formed by decomposition of common lubricants of several types. R. L. Johnson, D. Godfrey and E. E. Bisson.*

2078—*Horizontal tail loads in maneuvering flight. H. A. Pearson, W. A. McGowan and J. J. Donegan.*

2084—*Strength properties of rayon-mat honeycomb core materials. W. J. Kommers.*

2085—*Stress-strain and elongation graphs for aluminum-alloy 75S-T6 sheet. J. A. Miller.*

N.A.C.A. Technical Memoranda

1251—*On the formation of shock waves in subsonic flows with local supersonic velocities. F. I. Frankl.*

1265—*Amplitude distribution and energy balance of small disturbance in plate flow. H. Schlichting.*

1267—*Theory of plane, symmetrical intake diffusers. W. Brodel.*

1279—*Two-dimensional symmetrical inlets with external compression. P. Ruden.*
1280—*Graphical determination of wall temperatures for heat transfer through walls of arbitrary shape. O. Lutz.*

N.A.C.A. Reports

922—*Characteristics of low-aspect ratio wings at supercritical Mach numbers. J. Stack and W. F. Lindsey.*
925—*Stability derivatives at supersonic speeds of thin rectangular wings with diagonals ahead of tip Mach lines. S. M. Harmon.*
928—*Analysis of performance of jet engine from characteristics of components. II—Interaction of components as determined from engine operation. A. W. Goldstein, S. Alpert, W. Beede and K. Kovach.*
919—*Accuracy of airspeed measurements and flight calibration procedures. W. R. Huston.*
909—*Laminar-boundary-layer oscillations and transition on a flat plate. G. B. Schuneuer and H. K. Skramstad.*
908—*Stability derivatives of triangular wings at supersonic speeds. H. S. Ribner and S. Malvestuto, Jnr.*
905—*Full-scale investigation of the aerodynamic characteristics of a typical single-rotor helicopter in forward flight. R. C. Dingeldin and R. S. Schaefer.*
899—*A general small-deflection theory for flat sandwich plates. C. Libove and S. B. Batdorf.*

A.R.C. Reports and Memoranda

2307—*The effect of a wind-tunnel fan on irregularities in the velocity distribution. J. H. Preston.*
2344—*Some mechanical properties of foamed Polyvinyl formal for use as an elastic stabilizer in sandwich structures. W. J. Pullen.*
2347—*Ground effect on the lifting rotor. Flt/Lt. Zbrozek.*
2358—*Revised charts for the determination of the static and take-off thrusts of a propeller. A. B. Haines and P. B. Chater.*
2359—*Measurements of twisting moment due to aileron deflections on a model Mustang wing at high speeds. G. Hughes.*
2369—*Note on a "scissors-type" of dynamic balance for control surfaces. R. A. Frazer.*
2373—*Experimental determination of the aerodynamic derivatives for flexural-aileron flutter of B.A.C. wing type 167. C. Scruton, W. G. Raymer and D. V. Dunsdon.*
2375—*Flight tests on "King Cobra" FZ.440 to investigate the practical requirements for the achievement of low profile drag coefficients on a "low-drag" aerofoil. F. Smith and D. J. Higton.*
2406—*The installation of an engine nacelle on a wing.*
Part I. Model tests on a symmetrical wing. R. Smelt and A. G. Smith.
Part II. Underslung nacelles on cambered wings. R. Smelt and F. Smith.
Part III. Pitching-moment changes due to nacelles. F. Smith and R. Smelt.
Part IV. Effects of fuselage and tractor airscrew. R. Smelt and B. Davison.

Thornton Research Centre, Aero Engine Laboratory

M.56/50—*Gear lubrication. The I.A.E. 3¼-inch centres gear rig as oil testing unit. J. R. Hughes.*

National Research Council of Canada

MA-219—*Two electrical analogies for the pressure distribution on a lifting surface. W. F. Campbell.*
ME-177—*Method for measuring the size of water droplets in clouds, fogs and sprays. N. Golitzine.*
MR-6—*Development of a wing flow apparatus for transonic aerodynamic tests. Staff of the Flight Research Section, Division of Mechanical Engineering.*

Civil Aeronautics Administration

T.D.R.62—*Development of aircraft windshields to resist impact with birds in flight. Part I. Collision of birds with aircraft in scheduled commercial operations in the Continental United States. P. Kangas and G. L. Pigman.*

T.D.R.63—*Polarization errors of two different omnirange antenna sprays. S. R. Anderson and H. F. Keary.*

T.D.R.74—*Development of aircraft windshields to resist impact with birds in flight. Part II. Investigation of windshield materials and methods of windshield mounting. P. Kangas and G. L. Pigman.*

Publications Scientifiques et Techniques du Ministère de l'Air

N.T.33—*La mésure des temperatures de flammes. P. Barret.*

237—*Les théories de la turbulence. L. Agostini and J. Bass.*

Royal Institute of Technology, Sweden

KTH-AERO TN.11—*On the theory of flutter and an iterative method of calculating the critical speed of a wing. Pentii Laasonen.*

Flygtekniska Forsokstalten, Ffa

33—*Buckling stresses of box-beams under pure bending. S. F. Eggwortz.*

J. LAURENCE PRITCHARD,
Secretary.

Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, Sussex.

WELLWORTHY

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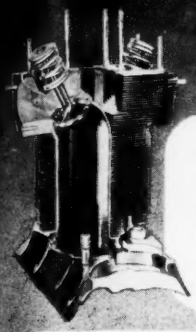

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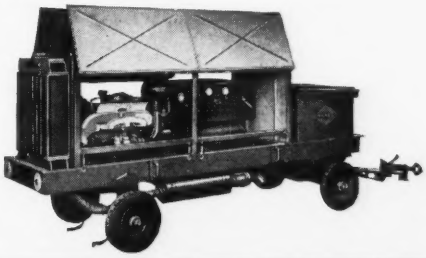

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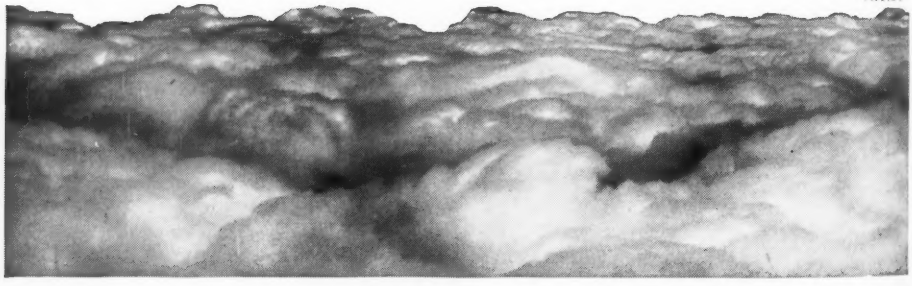

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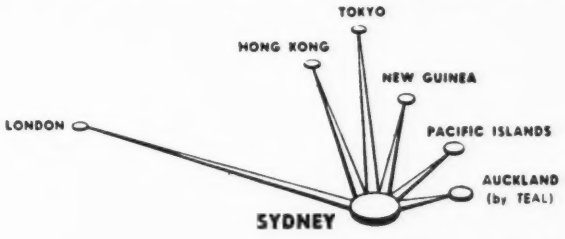

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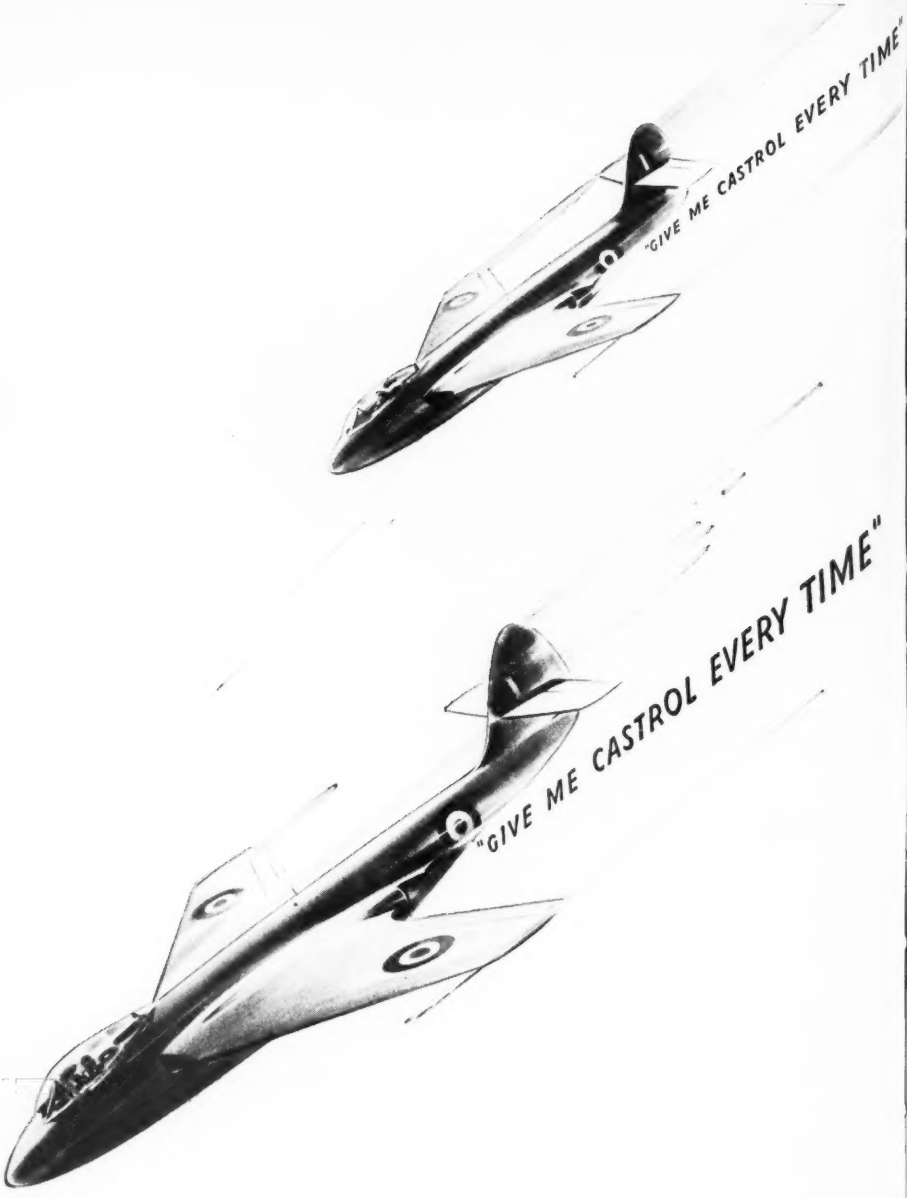

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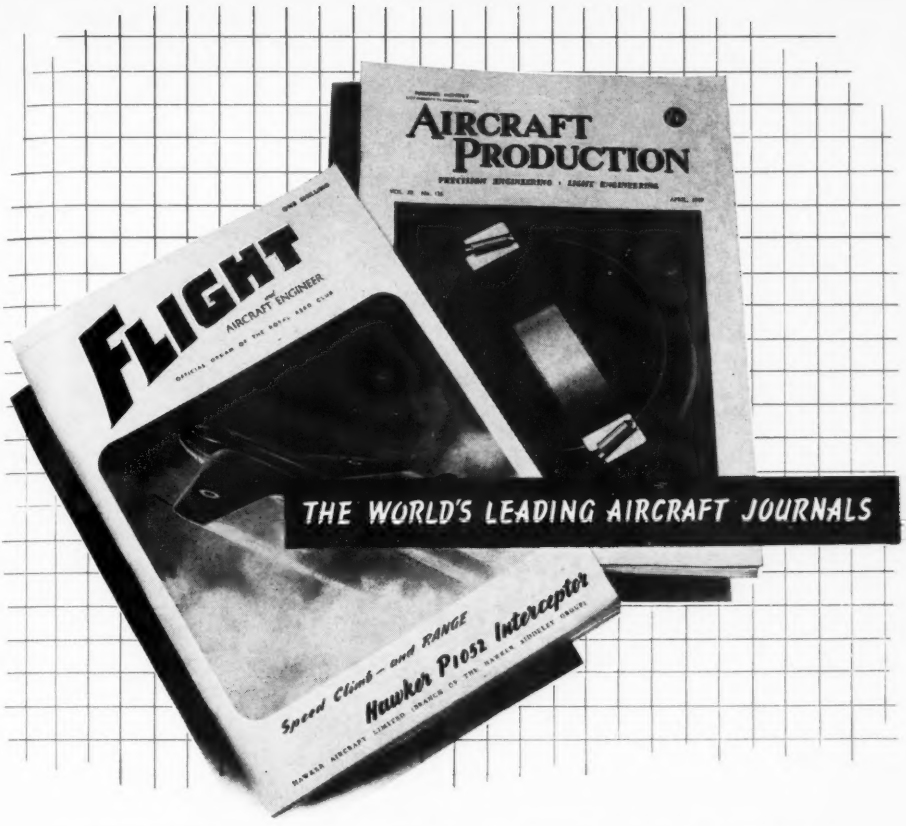

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THE AERONAUTICAL QUARTERLY

Volume II MAY 1950 Part I

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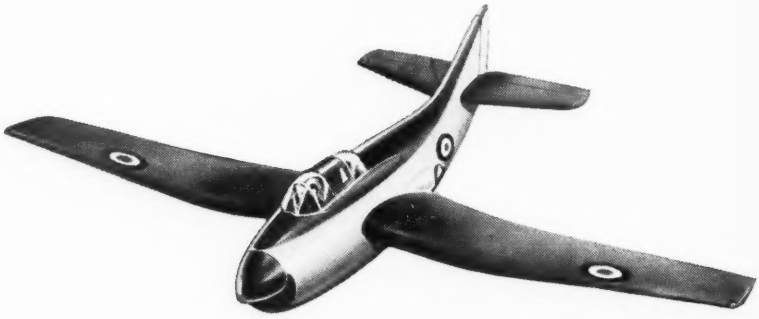

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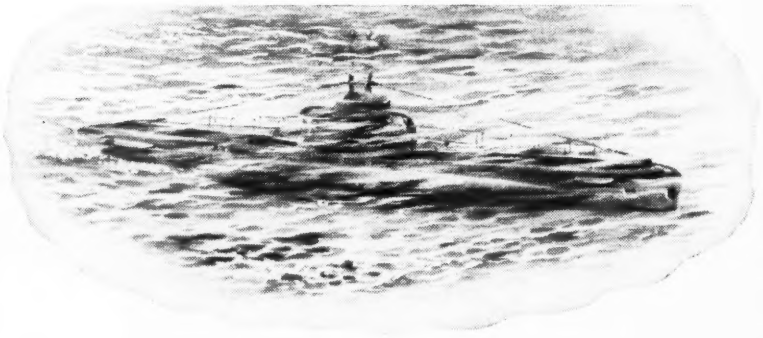

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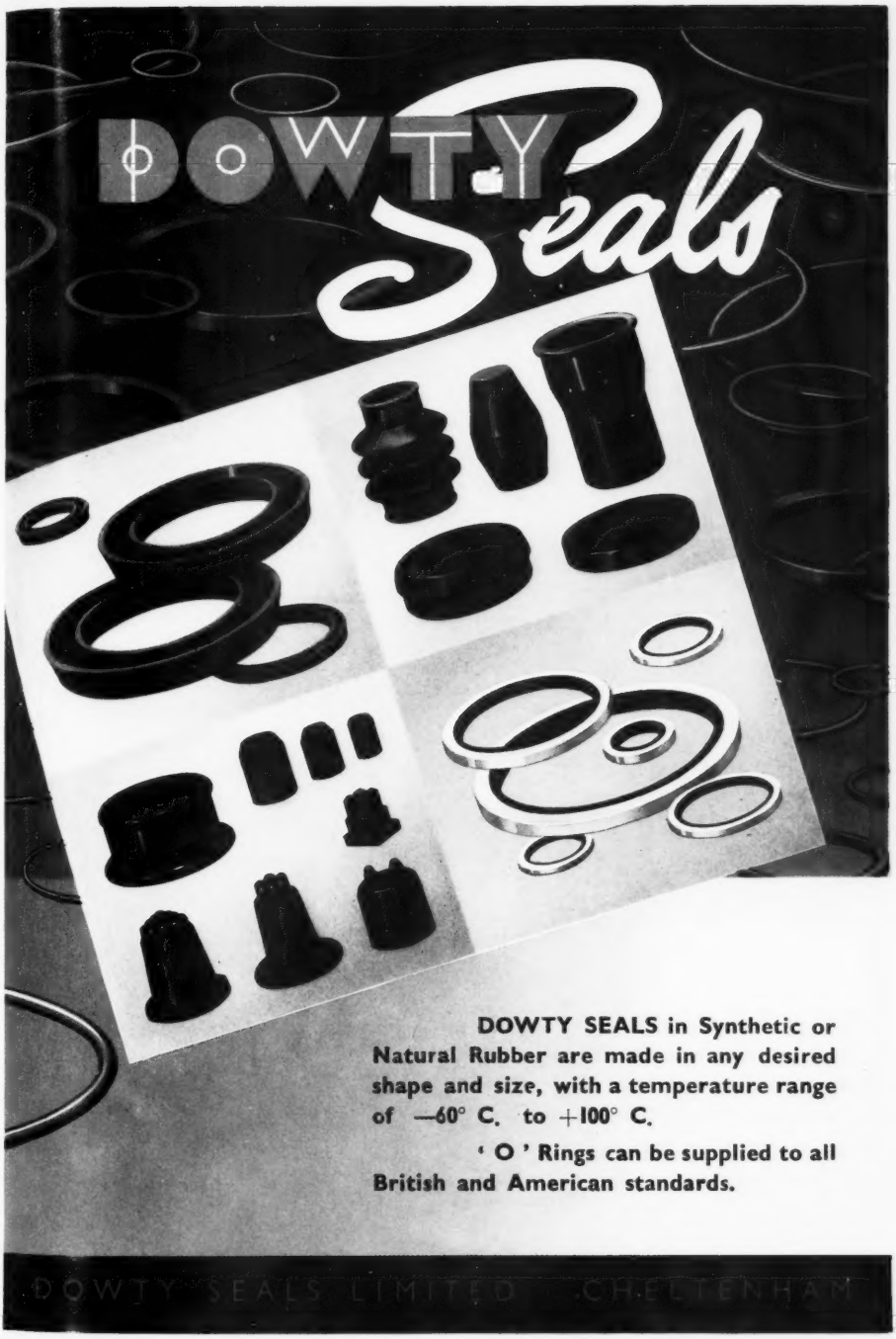

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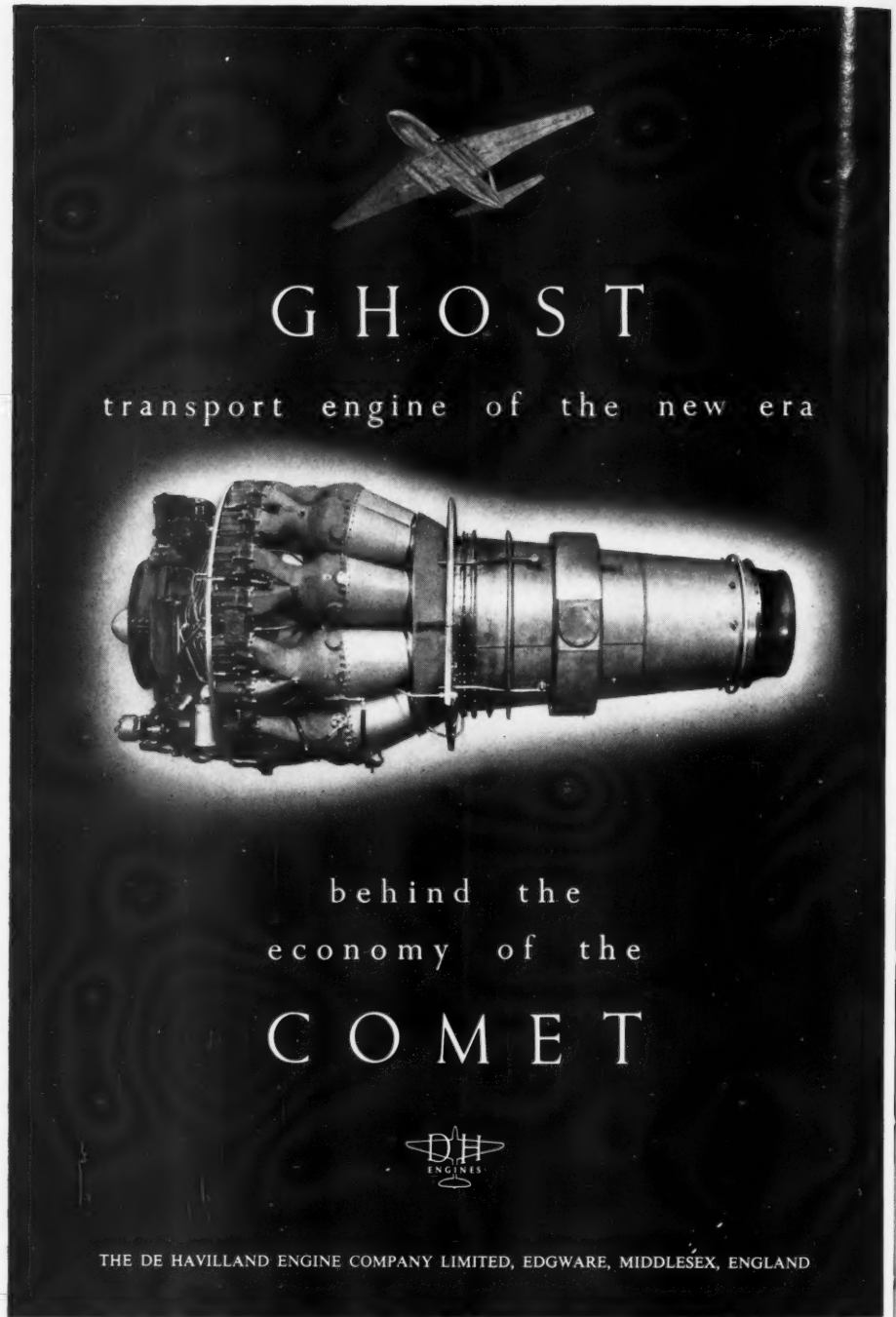
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Papers must be in English, in the third person, and typed on one side of the paper only, with double spacing and wide margins. When submitted they must be in their *final form for publication.* Only typographical errors may be corrected in proofs. Titles of papers should be brief.

Where practicable, a summary of not more than 250 words should be given at the beginning of the paper, giving its scope and conclusions.

All references should be numbered in the text where they occur, and the complete list of references given at the end of the manuscript. These references will be published at the end of the text. Footnotes should be numbered consecutively. Tables should be kept as concise as possible.

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Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.

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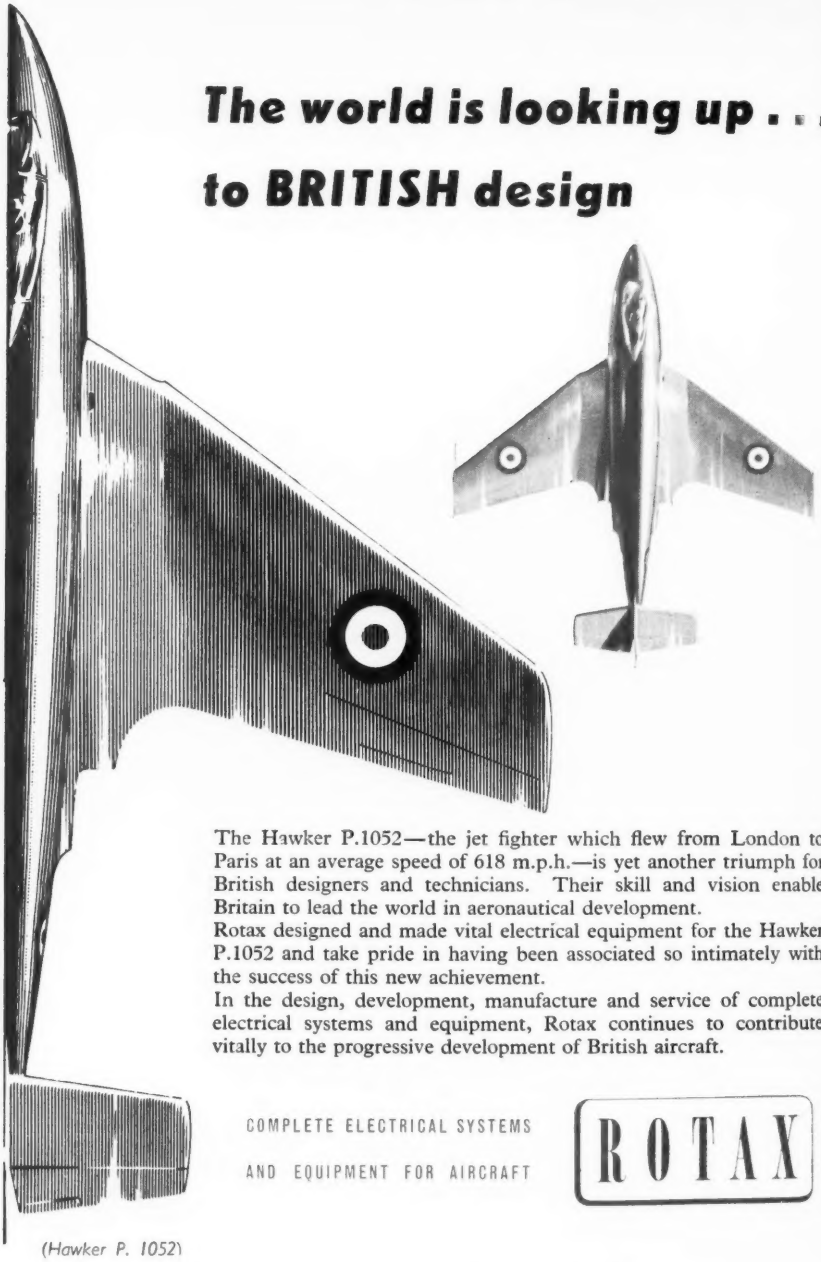

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38th WILBUR WRIGHT MEMORIAL LECTURE

SOME ASPECTS OF EXPENDITURE ON AVIATION

by

Sir RICHARD FAIREY, M.B.E., Hon.F.R.Ae.S.

MEDALS AND PRIZES were presented and the Thirty-eighth Wilbur Wright Memorial Lecture was delivered before the Royal Aeronautical Society at The Royal Institution, London, W.1, on Thursday 25th May 1950. Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., President of the Society presided.

The President: The presentation of the Wilbur Wright Memorial Lecture annually, on the inspiration of Mr. Griffith Brewer, of happy memory, to commemorate Wilbur and Orville Wright's pioneer flight in 1903, had been started just after the death of Wilbur Wright in 1912, and had become increasingly recognised as the outstanding event of its kind in the aeronautical calendar.

It had seemed fitting, therefore, on the present occasion—in the year following the Society's incorporation by Royal Charter—to send on the Society's behalf the following message of greeting to His Majesty the King:—

"The President, Council and all Members of the Royal Aeronautical Society on the occasion of the 38th Wilbur Wright Memorial Lecture, humbly send their loyal greetings to His Most Gracious Majesty the King, their Patron."

His Majesty's gracious reply was as follows:—

"Please convey to the Council and Members of the Royal Aeronautical Society, assembled to hear the 38th Wilbur Wright Memorial Lecture, the sincere thanks of The King for their message of loyal greetings which His Majesty, as Patron of the Society, much appreciates."

The following messages of greeting had also been exchanged with the Institute of the Aeronautical Sciences in the United States:—

"The Wilbur Wright Memorial Lecture by your eminent Past President Sir Richard Fairey stands as another milepost on the road to Aeronautical Knowledge. The Institute send greetings to both the Society and Sir Richard with assurance of continued close co-operation between the aeronautical scientists of both countries."

S. PAUL JOHNSTON,
Director.

"The President and Council of the Royal Aeronautical Society much appreciate your cable on occasion of the delivery of the 38th Wilbur Wright Memorial Lecture by Sir Richard Fairey and Respond with warm greetings to the Institute of the Aeronautical Sciences with whom we share the objective of advancing aeronautical knowledge and achievement for the good of mankind. We are all looking forward to our next conference in September 1951 and the opportunity it will give to meet so many of our friends."

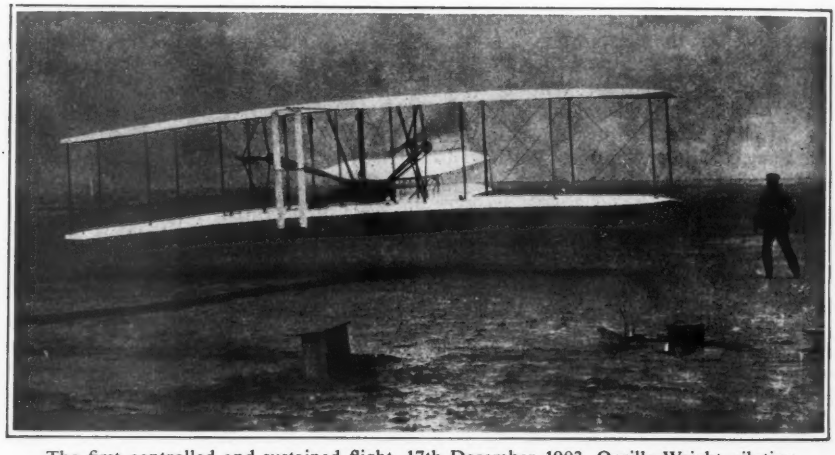
PRITCHARD,
Secretary.

It was the custom on the occasion of the Wilbur Wright Memorial Lecture, to present the Medals and Awards which had been conferred by the Council for work done in the preceding year and he had much pleasure in making on behalf of the Council the following presentations:—

The Society's Gold Medal—the highest honour it could confer—for work of an outstanding nature in aeronautics, was awarded to Sir Geoffrey de Havilland.

The initials "D.H." were engraved for all time on the world's history of aviation. Sir Geoffrey was one of the most modest of men and would have said it was a "team job" as it was, because he would have chosen the team. It was unfortunate that his absence abroad prevented his attendance but in his absence no one was more fitted to accept the Gold Medal on his behalf than Mr. C. C. Walker.

The Society's Silver Medal—for work of an outstanding character in connection with aeronautics, not often awarded since its inauguration in 1909, had been awarded this year to Mr. J. Smith, Chief Designer, Vickers-Armstrongs (Supermarine) Ltd. for his work on the design and development of high performance R.A.F. and Naval aircraft and to Mr. W. E. W. Petter (who was unable to be present) for his work on high performance aircraft. Mr. Petter's name would always be connected with the "Canberra."



The first controlled and sustained flight, 17th December 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

The Society's Bronze Medal—for work leading to an advancement in aeronautics, was first awarded in 1908 and had been awarded only six times. This year it was awarded to Mr. A. C. Lovesey, Chief Development Engineer, Rolls-Royce Ltd., for his contribution to engine development; he had been intimately connected with the progress of British engines and recently had delivered to the Society a classic paper on the development of the gas turbine.

The British Gold Medal—awarded for outstanding practical achievement leading to an advancement in aeronautics, had been awarded five times only since 1934. This year it was awarded to Major F. B. Halford, Chairman and Technical Director, de Havilland Engine Co. Ltd., in recognition of his work on engine design.

The British Silver Medal—awarded for practical achievement leading to an advancement in Aeronautics, was awarded to Group Captain P. W. S. Bulman (formerly Hawker Aircraft Ltd.) and Captain J. Summers, Chief Test Pilot, Vickers-Armstrongs Ltd.—both test pilots of over twenty-five years continuous experience.

Scientists, engineers and inventors might evolve new types of aircraft, but it was the test pilots who put them through their paces.

The George Taylor, of Australia, Gold Medal—awarded for the most valuable paper read during the previous session, was awarded to Mr. E. J. Richards, Assistant Chief Designer, Vickers-Armstrongs Ltd., for his paper on "A Review of Aerodynamic Cleanness."

The Simms Gold Medal—awarded for the most valuable contribution read before, or received by the Society on any subject allied to Aeronautics, was awarded to Dr. D. E. Adams and Dr. A. N. Uttley for their paper on Navigational Systems and Instrument Aids.

The Edward Busk Memorial Prize—awarded for the most valuable contribution read before, or received by, the Society on Applied Aerodynamics was awarded to Mr. D. L. Ellis for his paper on "Industrial Wind Tunnels."

The Branch Prize—awarded for the best paper read before the Branches during the previous lecture session was awarded to Wing Commander E. A. Harrop, R.A.F., for his paper on "Planned Servicing in the R.A.F." This lecture was read before the Brough Branch of the Society, and was the second occasion on which a lecture read before that Branch had been awarded the prize. Wing Commander Harrop was serving overseas and the prize would be received by Mr. F. W. Wilkinson, Secretary to the Brough Branch of the Society.

The Pilcher Memorial Prize—awarded for the most valuable paper read by a Graduate or Student at any meeting of the Society, or of its Branches, was awarded to J. Hahn for his paper on "Training of Aeronautical Engineers" read before the Bristol Branch of the Society.

The Orville Wright Prize—a new prize awarded for the best contribution received for publication in *The Aeronautical Quarterly* of the Society, on some subject of a technical nature in connection with Aeronautics, was awarded for the first time to G. W. Trevelyan and D. R. Blundell for their paper on "The Determination of the Drag of Jet Propelled Aircraft in Flight."

The R. P. Alston Memorial Prize—awarded for practical achievement associated with flight testing of aircraft was awarded to F. G. Hemsley for his valuable and careful work as a flight observer.

The Usborne Prize—awarded for the best contribution in the Society's publications, written by a graduate or student on some subject of a technical nature in connection with Aeronautics was awarded to C. M. Britland for his paper on "Helicopter Hovering Performance."

Honorary Fellowship—one of the greatest honours which the Society could confer on its Members. The number in this class of membership was limited by the By-Laws to 35 in all. He had much pleasure in announcing that the following, all pioneers of great achievement, had been awarded Honorary Fellowship:—Mr. Robert Blackburn, Sir Richard Fairey, Sir Francis McClean, Lt. Col. Mervyn O'Gorman and Mr. T. O. M. Sopwith.

Honorary Companionship—Another carefully guarded award was that of Honorary Companionship. The number of Honorary Companions was limited by the By-Laws to 10 and it was only awarded to those who were specially distinguished in the work they have done in furthering Aeronautical Science and Engineering. This year four awards had been made:—Marshal of the Royal Air Force Lord Douglas of Kirtleside, Air Marshal Sir Alec Coryton, Major Sir Hew Kilner and Mr. C. G. Grey.

Sir Richard Fairey who was to deliver the Wilbur Wright Memorial Lecture was in every sense most eminently suitable for that honour. He had begun his career in aviation in 1911 with the Blair Atholl Aeroplane Syndicate and then joined Short Brothers as Chief Engineer. In 1915 he founded the Fairey Aviation

Company Limited of which he was Chairman and Managing Director. In 1942 he became Director-General of the British Air Commission in Washington, which post he had held until the close of the war. From his achievement in aeronautics and his exceptional dealings with America during the war, there were few more fitted than Sir Richard to present the Wilbur Wright Lecture.

Some Aspects of Expenditure on Aviation

WHEN one is honoured by the invitation to deliver the Wilbur Wright Memorial Lecture one's immediate concern is to find a subject worthy of the occasion, which (in view of the wide coverage of the field of aeronautics that already has been made in these Lectures) is no easy task, at least to those of us who have no specialised knowledge wherewith to take advantage of the many new technical developments that continue to emerge.

In choosing my subject and in the attempt to draw, within a reasonable margin of error, an overall picture of the human effort that has been devoted to the cause of Aviation, I realise that I have bitten off a very large mouthful, and that some apology is due for the degree to which I may fail properly to masticate it.

On 17th December 1903 the Wright brothers started something, when by the achievement of human flight they opened the road to the tremendous developments in aviation that have taken place in this last half century. This vast and rapid progress in the technology of design, manufacture and operation of the aeroplane is today accepted as a commonplace, and its continuance taken for granted.

Fifty years ago, at a time when for a century past invention had followed upon invention, time and space were shrinking rapidly with the advances in the means of transport and communication, when the railways were considered to have conquered the land, and the steamships the sea, and the submarine was a known quantity, the air was the only domain still open to the human explorer, or so at least it was then considered. Certainly since that time man has achieved that conquest and to an extent unforeseen by the most optimistic prophets.

When searching for a possible yardstick to lay over this victorious field it is manifest that one does not exist that could give a complete picture, or throw it into true perspective. From any aspect it can be regarded only in terms of the standard of measurement used and with all the errors that that standard introduces. Obviously, widely varying qualities cannot be measured with the same instrument.

Nevertheless, with some standards, provided that we appreciate their shortcomings, we can at least make a relative measurement of achievement, and in considering those with the least margin of error one comes almost inevitably to the nowadays somewhat unfashionable standard of money. Before proffering a picture based on that standard, it is necessary to consider its shortcomings, prominent among which is the fact that, in common with most other standards, the larger it is the more nebulous it becomes. In these days we still must count the pennies, or the dollars, and in relatively small amounts they convey a very clear picture in our minds, but the more plentiful the millions, the less would seem to be the regard in which they are held, at least by those in charge of them.

Money, or rather currency, has other drawbacks as a standard of measurement. It shrinks remorselessly with the passage of time. Here I am not referring to the well-known phenomenon as applied to our personal bank balances, but to that process of creeping inflation whereby the ostensible value of money decreases continuously and at an increasing rate, as exemplified by the wages of an Elizabethan mason at 6d. a day, or the Victorian farm labourer at 2s. 6d. a day, which by present standards would not suffice for bare existence, but these people managed to live and raise large families.

While this shrinkage occurred only by steady degrees it reflected in some measure the increasing productivity of a human being. This process, however, has been greatly enhanced since the gold standard was abandoned and currency became the subject of manipulation by Governments, either in search of national advantage, or under the compulsion of events.

The lapse from the international gold standard has had the further effect that it renders much more difficult a comparison of effort as between different countries, even highly industrialised ones. The £ sterling has slipped some 30 per cent. since I started

work on this Lecture, fortunately too late to affect any figures quoted.

Another tempting standard is the modern one of the man-hour, first used, I believe, by Robert Owen, but on closer examination it varies even more widely between countries and standards of living, and is impossible to use outside the sphere of manual labour, and even there it varies between skilled and unskilled labour, and still more so between highly industrialised civilisations and more backward ones. When forced or slave labour is concerned it fails altogether.

Still less does it suffice to measure human effort in terms of mental activity, the application of acquired knowledge, or where invention or sheer genius is involved. What, for example is the value of the man-hour or less in which Hubble conceived the vision of an expanding universe, or which the Wright brothers put into the conception of their first aeroplane? The suggestion that all man-hours are of equal value because all men's basic physical needs are much the same is the cause of much fallacious political thinking.

Therefore, for the purposes of this Lecture, in the attempt to portray the human endeavour that has been applied from those early days to the present time in achieving the conquest of the air, I have chosen the standard of currency. Ounces or tons of gold would do equally well, and in some ways better, but would convey no picture to the human mind, particularly in these days when we never see even the smallest coin of that material.

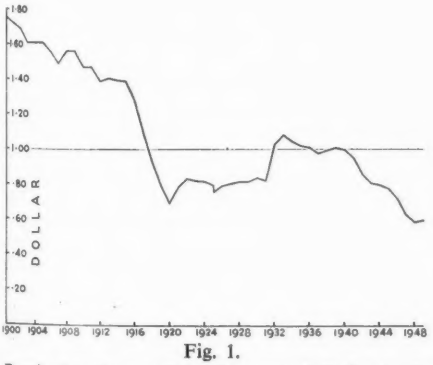


Fig. 1.

Purchasing Power of the Consumers' Dollar in the United States.

(*From table supplied by U.S. Department of Labour, Bureau of Labour Statistics.*)

In choosing the most suitable currency to serve as a yardstick over the past 50 years, the obvious selection is the dollar, since over that period it has suffered the least change. Nevertheless, in considering its value in purchasing power of manual labour, or ordinary commodities, we have to face the fact that our yardstick has shrunk by some 66 per cent of its original length. It is as if we sought to measure a plot of land with an elastic tape measure that contracted erratically, and sometimes expanded, while we were at work, and by the time the job was finished had shrunk to one-third of its original length.

Illustrating this point I give in Fig. 1 the value of the consumer's dollar as computed by the United States Bureau of Labour Statistics. It will be noted that the shrinkage is far from uniform, indeed it nearly all takes place in the periods between the beginning of the century and the end of the First World War, and that from the beginning of the Second World War and the present time. For the first decade after 1922 it remained remarkably steady. Moreover it was of almost exactly the same value in 1918 and 1940.

Figures 2 and 3 give the corresponding wage rates in Great Britain and the United States. Both show the same general pattern although the British one, of course, takes no account of the large food subsidies and social services which have considerable effect upon the apparent basic rate.

It would avail little to use an average dollar over the whole period as the standard, particularly in converting to dollar values the other currencies concerned. Moreover, the volume of work done is by far the greatest at the period when the dollar is declining towards its lowest and when wages are rising in the same order to offset the change. Accordingly, in all the figures that I shall quote hereafter, and in the illustrations, all currencies have been converted at the rate pertaining for the year in question. The rates of exchange used are, for each financial year, the Federal Reserve Bank's average of certified noon buying rates on New York for cable transfers.*

The collecting of the necessary statistics wherewith to portray the expenditure on aviation, in terms of currency, from its start to the present day not unexpectedly proved to be a formidable task. The records

*All billions of dollars are the U.S. billion, *i.e.* 1,000 million.

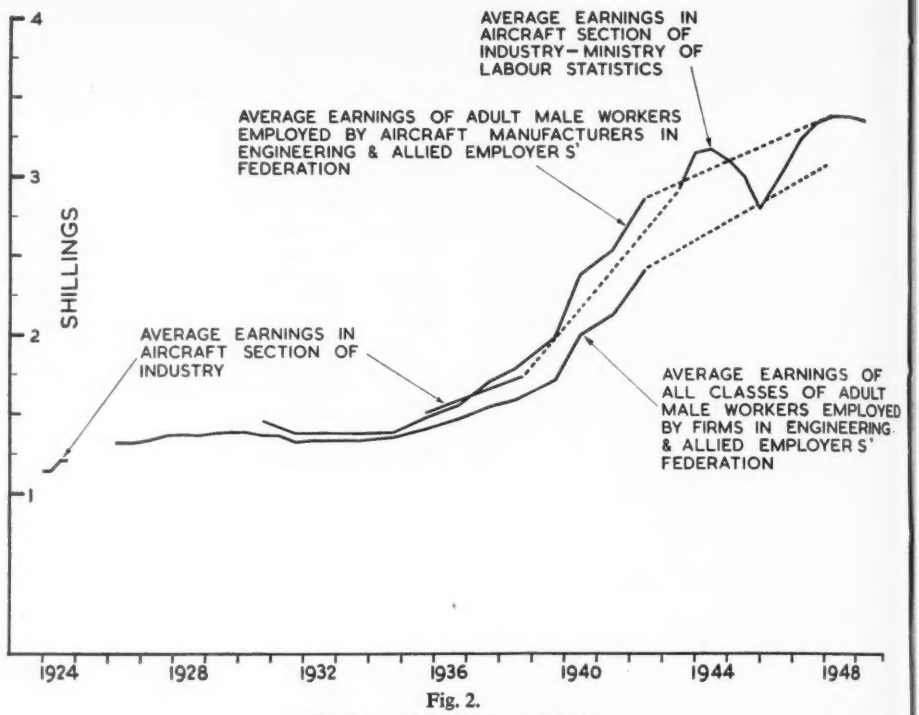

AVERAGE EARNINGS IN AIRCRAFT SECTION OF INDUSTRY—MINISTRY OF LABOUR STATISTICS
AVERAGE EARNINGS OF ADULT MALE WORKERS EMPLOYED BY AIRCRAFT MANUFACTURERS IN ENGINEERING & ALLIED EMPLOYER S' FEDERATION
SHILLINGS
4
3
2
1
AVERAGE EARNINGS IN AIRCRAFT SECTION OF INDUSTRY
AVERAGE EARNINGS OF ALL CLASSES OF ADULT MALE WORKERS EMPLOYED BY FIRMS IN ENGINEERING & ALLIED EMPLOYER S' FEDERATION
1924
1928
1932
1936
1940
1944
1948

Fig. 2.
Hourly earnings in Great Britain.
(Earnings in Federated Firms supplied by Engineering and Allied Employers' Federation.)

vary immensely in availability, method of accountancy and presentation, and as between different countries and periods of time.

In the parliamentary-governed countries accounts have to be rendered covering all government military and civil expenditure, albeit sometimes presented in a form that makes it very difficult to allocate as between Services, and subject always to the requirements of secrecy in such questions as research. In the totalitarian states few records ever are published, particularly military. Between them one is confronted with such extremes as the carefully compiled and complete statistics of Civil Aviation in the United States and Great Britain and the relative absence of figures from behind the Iron Curtain. It has been found possible, however, by comparisons of aircraft mileage, passenger and freight traffic and so forth, to arrive at figures which after cross-checking with other available sources at least provide a relative basis of comparison.

Likewise, apart from direct Government expenditure and subsidies, where questions such as private and charter flying, air survey, demonstration, and the like are concerned, despite again the variation in available records, a considerable amount of information can be found and reduced to the required form. For example, in the United States non-scheduled flying is recorded by the Civil Aeronautics Administration in terms of total flying and fuel consumption. In the United Kingdom the Air Ministry or Ministry of Civil Aviation's Reports on the Progress of Civil Aviation are available, usually in terms of miles flown, and can be compared against the type of machine used.

The principal airline companies publish comprehensive annual reports giving information additional to that needed by their accounts, and generally have been most willingly helpful in providing statistics.

A particular difficulty in certain cases has been the accurate inclusion of expenditure on new aircraft where the figures for such, and

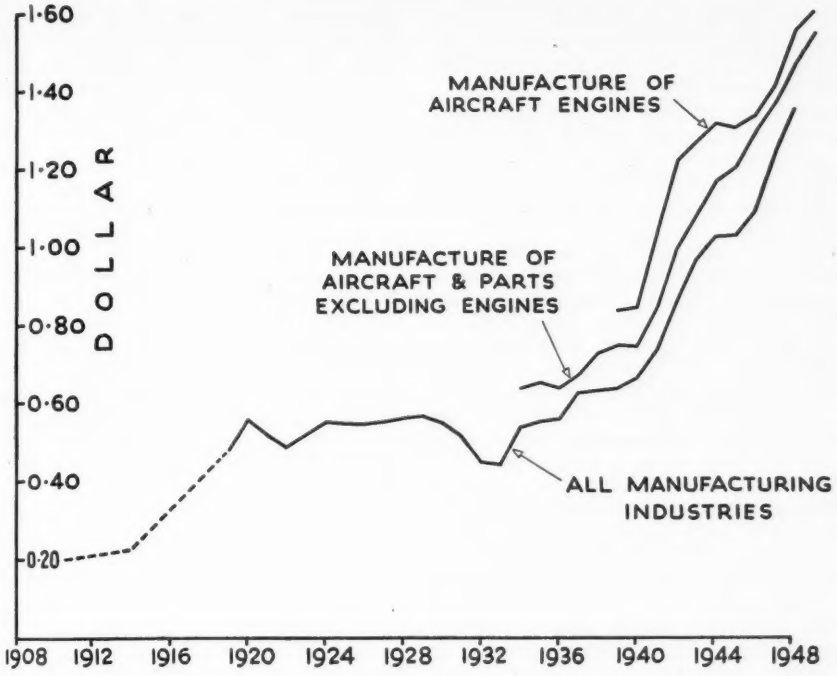


Fig. 3.
Hourly earnings in United States.
(*U.S. Department of Labour Bureau of Labour Statistics*)

the corresponding rate of depreciation, are not to be found in the published accounts, and State financing has been involved, sometimes in the form of providing the aircraft, either free or at less than cost, in lieu of direct subsidy. Some such cases could only be dealt with by counting the total cost as being made up of Government expenditure, including subsidy, plus the trading revenue of the airlines concerned. This assumption should be within reasonable limits, as it is taken for granted that losses generally have been made up, or that if there was any profit then no subsidy would be involved.

Among non-scheduled flying what is known as joy-riding accounts for a surprisingly high mileage in earlier days.

Air survey is almost entirely absorbed in Government expenditure, either as direct operators themselves or by contract to private concerns. That business has few private customers.

One of the worst sources of error is involved by the inter-mixing of civil and military activities during the War, or where as in Germany, military activity and training has been deliberately camouflaged as civil. In that particular case I have been forced after 1933 to record all German expenditure as military, apart from the airlines.

A relatively small inaccuracy is introduced by the variation in the financial year of different countries. This, of course, averages out over the longer periods.

In submitting the results of this investigation every reservation is made for the margin of error arising from the difficulties of extracting the figures from incomplete or insufficiently detailed records, and from the necessity of resorting to estimate to fill in the gaps where none at all are available. Such estimates have been based on the general level of costs that have emerged from the study of similar operations elsewhere.

Fortunately for the overall accuracy of the picture, the amounts involved, with the exception of the Russian, are utterly dwarfed in comparison with the enormous Govern-

ment expenditure, and in those democratic countries where such expenditure is the greatest, it can be said that the greater the outlay the better is the record.

Due to the absence of complete figures after 1948 I have been forced to terminate this survey there, or rather at the end of the financial year 1948-49 which is March 1949 for the United Kingdom or June 1949 for the United States.

With these facts in mind, let us look first at the cost of the individual aeroplane which is meaningless unless examined in close relation to its size, speed, equipment and many other characteristics, particularly its potential life. Such a detailed analysis would be outside the scope of the present subject. Nevertheless, it is of passing interest to recall some of the figures of the early days and to compare them with those of the present time.

Many of the pioneers worked with their own hands, even when as the Wright brothers did, they employed other help. I believe that Mr. Taylor, their mechanic, was paid $15 a week. The cost of the very early aircraft was mostly that of materials and the engine, if that were purchased separately.

The original Wright Flyer, which weighed only 605 lb. empty, is said by Orville Wright himself to have cost between $1,000 and $2,000, and the same applies to the first batch of six built in 1907.

Sir Francis McClean still has the receipt from Orville Wright for Flyer No. 3, at £1,000, then equivalent to $4,865.

It is when the aeroplane was first built for sale that we can get a closer measure of its cash value. For example, the Farman Biplane was advertised for sale in 1908 at $5,840. The Voisin exhibited at the Olympia Show in 1909 was priced at $4,620 but guaranteed to fly for 3 miles, and Lord Brabazon's original Bird of Passage, another Voisin, flown by him in 1909, cost him $4,860, plus $3,400 for the engine, as compared with Mr. Glenn Martin's aircraft of the same year at a price of $4,200.

A little later the Handley Page Company was quoting $1,825 for a single-seater, and M. Santos Dumont $1,700 for a Demoiselle.

In fact it seems from a search of the records for the years from 1909 to 1914 that the price fell generally within the range of $1,500 to $10,000, including an order for six Short Seaplanes purchased by the Admiralty at a price of $9,750 apiece, less engine, and it is interesting to note that the British and Colonial Aeroplane Company (now the Bristol Aeroplane Company) founded in 1910, built in that period 77 Box-Kites which were sold at $4,840 to $5,700 apiece, and a number of other types, none of them costing more than $6,000 each, including the engine.

Since those days we have seen the aeroplane grow rapidly in size, speed and standards of passenger comfort to such modern examples as the Boeing Stratocruiser at the empty weight of 83,500 lb. for $1,500,000 and a cruising speed of up to 340 m.p.h.; the DC-6 at 53,500 lb. for $750,000 and 310 m.p.h. or the jet-engined Comet at 46,830 lb. for approximately $1,200,000 and 490 m.p.h.; and still we have small two-seaters, such as the Piper Cub, for $2,795, that is in the same order of price as the earliest types.

Examination of the price of aeroplanes in terms of cost per lb. tare weight again has little meaning in light of other variables, but does disclose the interesting point that the average has risen throughout only in the ratio of three to one, or by the same degree as the dollar yardstick has shrunk. The earliest aircraft were from 5 to 10 dollars a lb. and remained in that region until about 1934 when the change in method of construction of the stressed-skin monoplane and the increasing complication of furnishing and equipment drove it upwards to from 12 to 18 dollars a lb. for modern piston-engined air liners and higher still with the increased cost of jet engines (Fig. 4).

This apparent constancy when allowing for the dollar shrinkage is merely coincidental and reflects the fact that the vastly increased complication of structure and elaboration of equipment, passenger comfort, and so forth, have been balanced by modern production methods and the greatly increased production.

An entirely different picture is presented if these comparisons are made on a basis of potential life, or rather in potential passenger-miles to be covered.

This cannot be computed for military aircraft as in peacetime they become obsolescent and sometimes are scrapped ruthlessly in favour of superior types, and in wartime many meet with violent ends, although the life of war aircraft is longer than might be expected. A United States Air Force Statistics Control Division letter

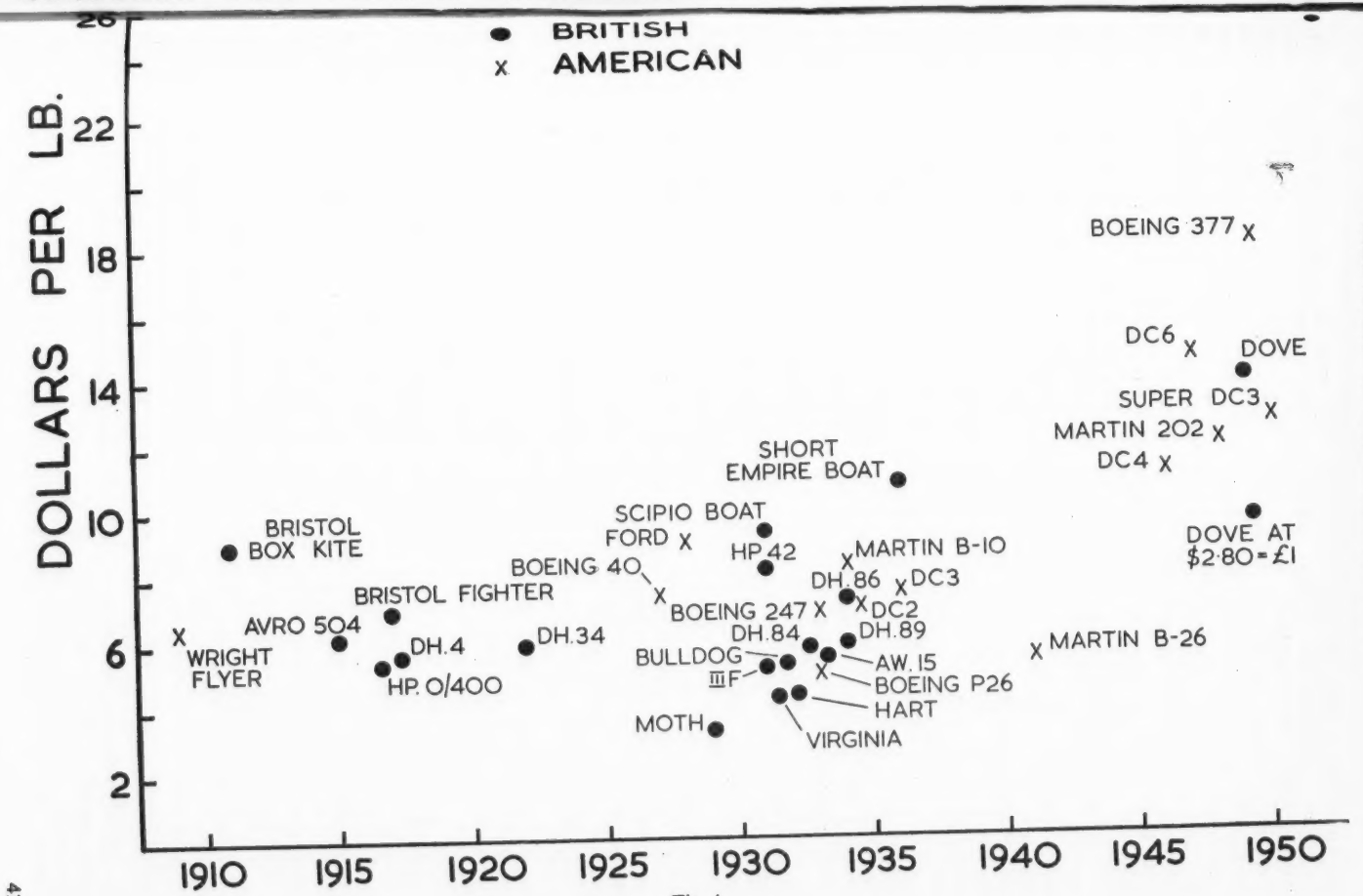


Fig. 4.
Prices of areoplanes for pound weight empty.
(Prices of British aircraft converted to dollars at average rate for the year.)

in April 1945 quotes a life of 10 months for a fighter, 12 months for a heavy bomber, and 42 months for a transport.

In civil use the potential life of the airframe itself has gone up from a maximum expectancy of an hour or so of flying time in the days of the flimsy wooden craft of the pioneers, to the modern monoplanes which have so increased in durability as to be good for a life in the order of 10 million miles.

Nor need this be the upper limit. With increased demands for additional strength and higher safety factors to cope with high speeds, with correspondingly increased stresses on encountering air disturbances, coupled with the advent of the jet engine with its reduction of vibration, and such things as improved materials, the aeroplane is likely to become ever stronger and longer lived. Therefore, we may look forward to a decreasing capital cost per passenger-mile provided that the greatest possible utilisation of the airframe is made before it is overtaken by obsolescence. In this the rise in cruising speed manifestly will have an important effect. In operation such jet aircraft as the Comet should be able to run off passenger mileage in half the time of the older and slower types.

This factor of ever-increasing life with its corresponding decrease in the capital cost per passenger-mile is the outstanding one revealed by any study of the cost of the individual aeroplane. From something in the order of a hundred dollars per passenger-mile in the very earliest types it has decreased until now it can be reckoned in fractions of a cent, and is still decreasing. It emphasises the basic cheapness of the aeroplane as a vehicle and holds out prospect of further reductions in the cost of flying.

The trends of capital cost of the aeroplane itself, reflecting as they do its growth in size and development as a reliable vehicle, are only small indications of the growth of expenditure on Civil Aviation over the past half century. It is this total expenditure that I now propose to examine.

In the attempt to get the picture into perspective and to portray the rate and degree of expansion I am relying only on the expenditure as giving the nearest to an overall picture of the human effort involved. The graphs submitted and the corresponding figures, therefore, give a one-sided picture and ignore the income altogether. Civil Aviation sometimes is conducted at a profit and sometimes at a loss, but by and large the income figures would reflect the same trends as the outlay. This expenditure aspect on Civil Aviation also compares directly with the Military where no question of income arises. Moreover, this ignoring of the question of profit or loss tactfully avoids any comparison between Government operations and private enterprise.

The substance of my remarks is in the accompanying charts which tell the story more fully and in less space than is possible in words, which can be used only to draw attention to the salient points.

Prior to the First World War, the only purposes served by Civil Aviation were the development of the vehicle itself under the stimulus of interested sportsmen, and the entertainment of the populace. Commercial operations were limited to manufacture and training, in neither of which can a firm differentiation between civil and military be made. Apart from a few experimental demonstrations there was no air mail until the United States Post Office began their Washington-Philadelphia-New York service on 15th May 1918 at a price of 24 cents a half-ounce, soon to be reduced to 16 cents.

Civil air transport proper begins after the First World War. In the United Kingdom and France it got away with a rush, somewhat optimistically, because of the attractions of the London-Paris service as a likely paying proposition. Handley Page Transport, Instone Air Line, Aircraft Transport and Travel Limited all started as private ventures and with a considerable measure of initial success. Soon on this route they encountered the competition of the subsidised French Compagnie Messageries Aériennes, which cut the fare from $34 to $22 in 1921.

In the United States the country was soon covered by a network of air mail lines which received their Charters by competitive bids for Post Office contracts. It was in 1926 that they first started carrying passengers on scheduled airlines on a serious scale, and official figures of mileage are available from that year onwards.

In Europe France took the lead, soon to be followed by Holland, where the K.L.M. was among the first operators in the world to spread out overseas. European companies also were operating abroad in the early 1920's.

Contrary to early hopes, however, the air age had not really arrived yet, and soon

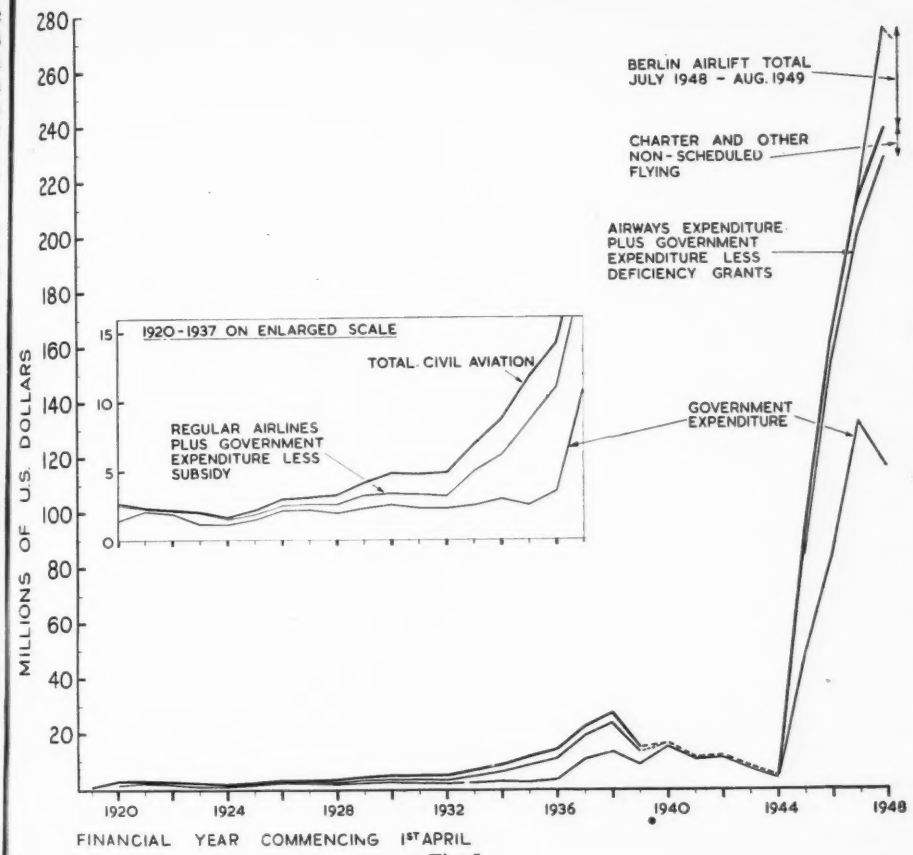


Fig. 5.
Expenditure on Civil Aviation. Great Britain.

Governments were coming to the rescue, not without self-interest with an eye to national advantage and to the maintenance of aircraft factories as an insurance against future military needs. In the first six years after the First World War the world level of expenditure remained at between 20 and 30 million dollars.

All countries remained at their respective levels, of which France and Germany were the highest, until about 1926, when scheduled passenger-carrying began in the United States, and the French, German and British graphs all start to lift, and a further definite rise starts about 1933 when a number of influences were at work (Figs. 5 and 6). This was the period of recovery from the world slump and the accession of Hitler to power, but one of the most important factors was the introduction of the all-metal monoplane—a great step forward in construction and efficiency, together with the increase in size that it made possible. The Boeing 247 made its appearance in 1933, followed by the DC-2 in 1934, and shortly afterwards, the DC-3. The Short Empire flying boat was in operation by 1936. There was a marked advance in passenger comfort, and regularity of service, and air travel as such began to take its place as a real competitor with other means of transport. This is the period when the civil aeroplane really took root.

This is further reflected in the big expansion of routes, which were becoming world-wide. Pan-American opened its trans-Pacific service in 1935 with Martin M-130

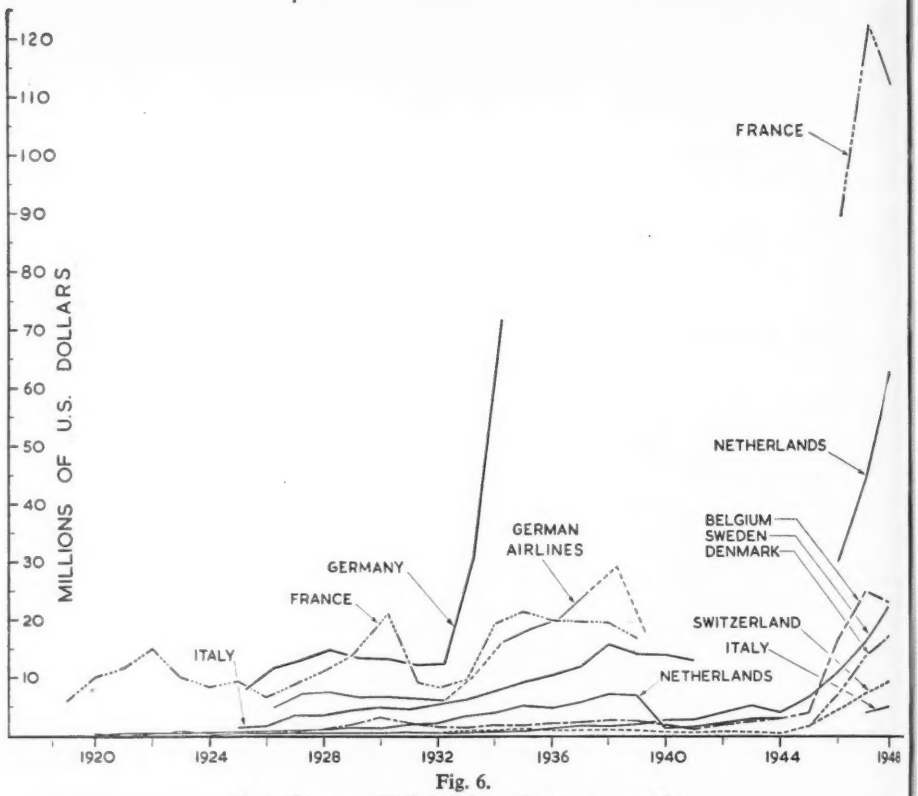


Fig. 6.
Expenditure on Civil Aviation. European countries.

flying boats, and Imperial Airways by that date reached out as far as Singapore and Cape Town.

Examining the graphs of individual countries during this period and until the outbreak of the Second World War (Fig. 7), the United States is most prominent by the steady increase of Civil air activities under the stimulus of the competitive air mail contracts, which paved the way for civilian transport and soon a network of airlines spread over the whole country, linking all the major towns; services rapidly improved in number and regularity, and in a few years the famous DC-3 was in a fair way to monopolise the picture.

Activity in the British Empire (Fig. 8) shows the same characteristics on a reduced scale to a peak of 60 millions in 1938, of which Great Britain supplied nearly half, and Canada and Australia one-sixth each. The drop in the curve from 1938 reflects the onset of the War. The exact point where this occurs is not depictable since it arises from the need of joining the points represented by the expenditure in the corresponding financial years.

The major European countries in general display the same trends, the apparently erratic course of French expenditure being partly due to fluctuations in the exchange rate, although other influences were also at work (Figs. 6 and 8).

In Germany the amalgamation of a number of air transport concerns into the Deutsche Lufthansa in 1926 formed the biggest single civil operating organisation in the world. Published figures of its expenditure in the first few years show a period of consolidation at between 6 and 7 million dollars.

In 1932 the German graph develops symptoms of altogether abnormal expansion that soon are to preclude it from being

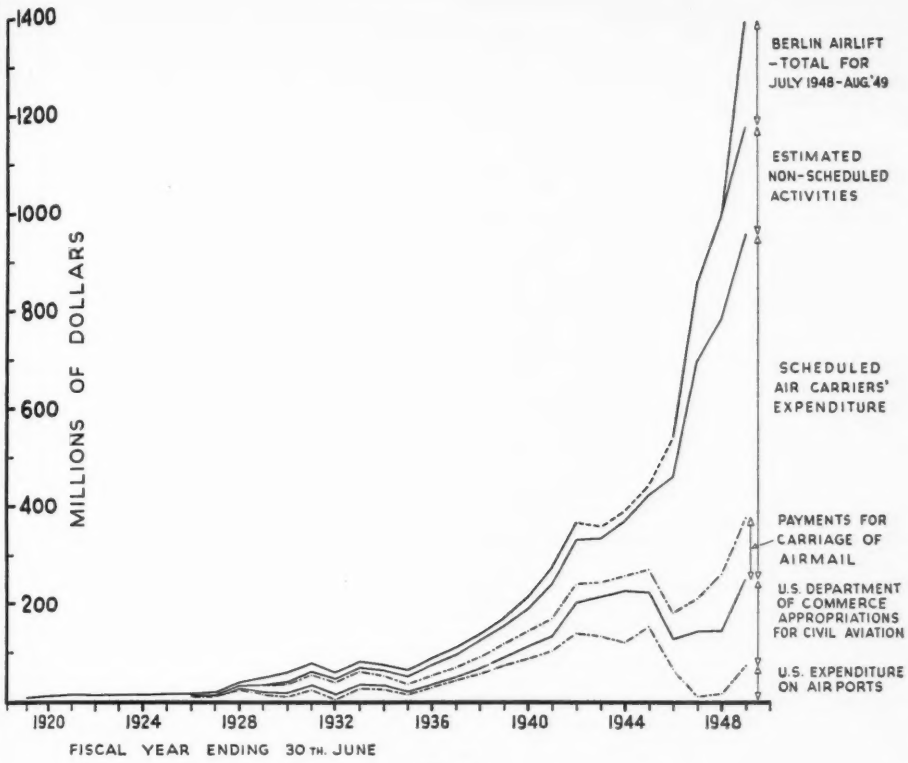


Fig. 7.
Expenditure on Civil Aviation. The United States.

reckoned as *bona fide* Civil Aviation expenditure. I have been forced merely to indicate its scope and after 1934 to revert to the expenditure on airlines only. Obviously with the advent of the Third Reich Germany, having cast off the restrictions imposed on her, was deliberately stimulating air activity to the limit of her resources.

Of the remaining countries Italy ranks high with a peak expenditure of 15 millions in 1938. Belgium and the Netherlands, largely by virtue of their overseas services, display considerable activity in proportion to their size, as also does Sweden.

The same general features are displayed on Civil Aviation expenditure in Central and South American countries, which I have lumped together for reasons of space (Fig. 9). Many South American airlines were pioneered by American or European concerns, as, for example, the early German activity in Colombia and Bolivia, and that of French subsidiaries in Brazil and the Argentine.

The Japanese figures, while lower than might have been expected up to the outbreak of the Pacific War, thereafter rise at a rate that is unacceptable as Civil Aviation, and the bulk of it must be accredited to military purposes. Since the War it has ceased altogether.

Chinese figures are extremely conjectural and complicated by the degree of American help accorded them, much of which was military. For a period after the War there is a great increase in activity. Passenger-mileage, which is estimated at $8\frac{1}{2}$ millions in 1936 (before their war) goes to a peak of 150 millions in 1946.

Of all the countries, Russia provides the greatest difficulty in arriving at any reasonable estimate of civil aeronautical operations,

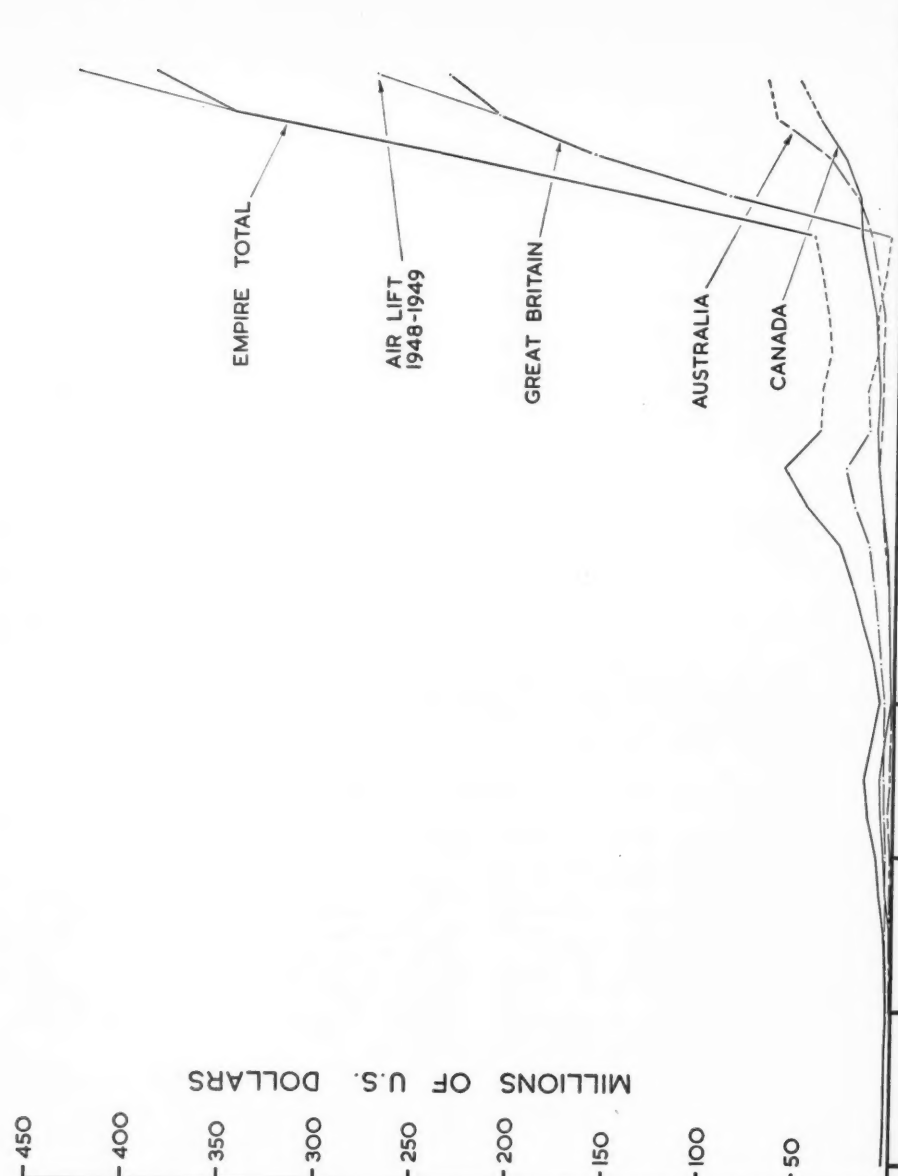


Fig. 8.
Expenditure on Civil Aviation. The British Empire.

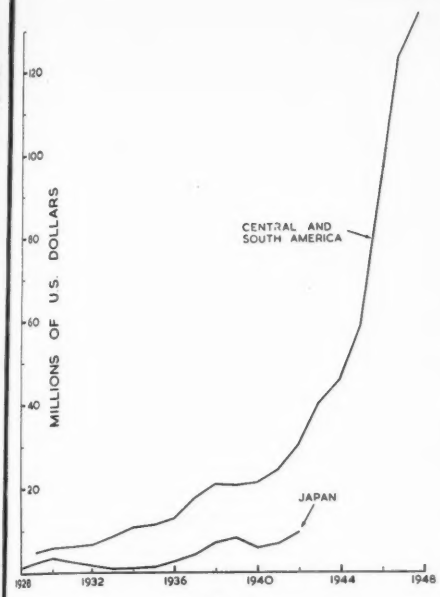


Fig. 9.
Expenditure on Civil Aviation. Central and South America; Japan.

nor are such figures as are available easily converted into units of expenditure. Well-founded statistics of numbers of passengers and route mileage are published by Mr. J. Parker Van Zandt, but there is no clue as to the total number of passenger-miles involved, and the only bases of comparison are the published civil air activities as a percentage of the total air vote up to 1929, and these reflect a considerable rate of growth. A large amount of Soviet civil activity is due to the carriage of freight and quite a proportion to mail carrying. Of later years there also appears to be considerable activity in such matters as crop-spraying, pest control, and other agricultural duties.

Nothing is recorded before 1927 and then only 200 passengers and 11 short tons of mail and by a rate of expansion comparable to that of other active aeronautical countries these had reached the figures of 358,000 passengers and 50,000 tons of freight by 1940. Over this period expenditure has been reckoned as having increased from a budget allocation equivalent to $1,700,000 to a figure of $30,000,000 estimated as reflecting the general order of activity, but such is the lack of any true basis of comparison or material for cross-checking that I have refrained from publishing a graph.

Civil activities in the remaining countries are proportionately too small to warrant separate treatment and have been merged into the world totals.

In many countries the increase in Government support from about 1934 in its various forms may well have resulted from their first reactions to the German activity on the civil side, as it does to a marked extent later on the military. By the outbreak of the Second World War, world expenditure on Civil Aviation had reached a total annual figure of 390 million dollars.

During the Second World War civil air transport as such diminished in many countries, and many of its functions were taken over by military air transport services, although in the United States it continued to expand at a considerable rate. In England also, Government money is still appropriated for civil purposes and the B.O.A.C. were running trans-Atlantic and other overseas services. In Europe, Sweden and other neutrals continued their operations, as did also the South American countries. Other countries ceased altogether, hence the gaps in the graphs.

Since the War the increase of civil aeronautical activity has been meteoric indeed, and in almost every country aircraft operation has leapt forward. From 1946 onwards Civil Aviation has doubled, trebled and quadrupled its position from that at the beginning of the War, and the rate of expansion shows no sign of slackening until 1948. But here again is a reminder of the weakness of the yardstick used; in this same period the value of the dollar in terms of labour and material has fallen relatively steeply. It is an inflationary period and by any other measure, for example that of passenger-miles flown, the rise, although still highly spectacular, would not be so great as when depicted in terms of expenditure.

The arithmetical sum of these annual figures gives a result that would be expected from examination of its components, except that there is an apparent drop in 1935, at which point I have ceased to include German figures, other than the scheduled airlines, and joining up the points of 1933 and 1935 would probably give a truer picture (Fig. 10).

The graph of totals reveals how great is the proportion of world activity due to the United States and the influence of the Berlin Air Lift is quite noticeable. It displays that

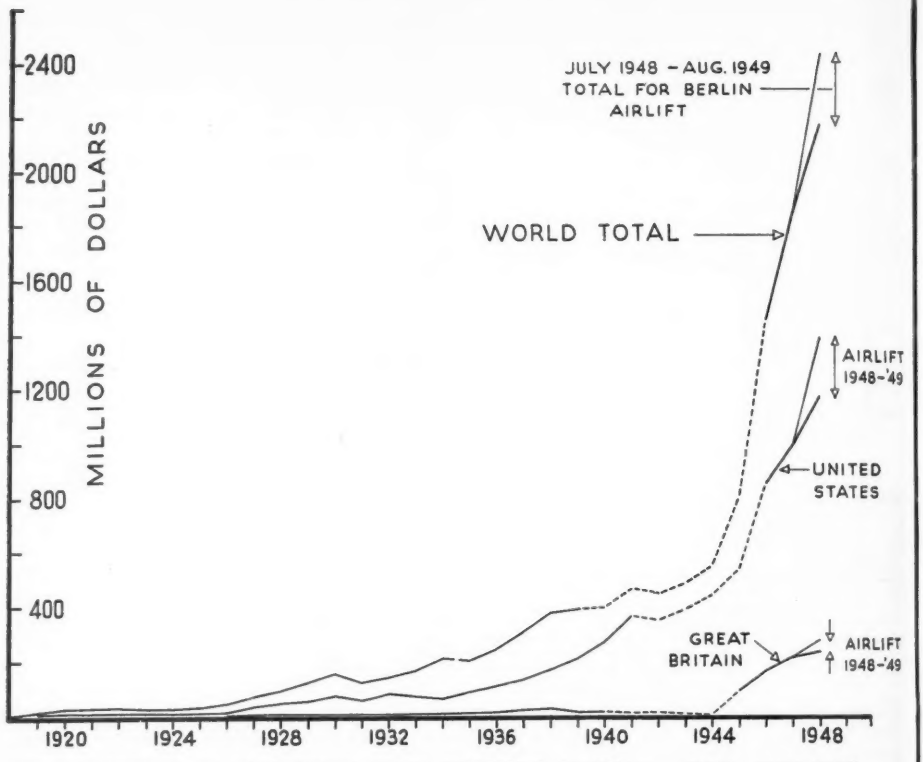


Fig. 10.
Expenditure on Civil Aviation. World total.

from its start after the First World War, expenditure on Civil Aviation had remained level, or even slightly reduced until 1924, had increased to over 200 million dollars in the next 10 years, and then to 390 million dollars by the outbreak of the war in 1939. By 1949, that is to say by the end of the financial year of 1948, but including the Berlin Air Lift, it had reached the sum total of 2,400 million dollars.

The accumulative totals are no less impressive. By 1932 it was 820 million dollars, by 1939 2,500 millions, and nearly a year short of the present day the total expenditure on Civil Aviation is assessed at no less than 11½ billion dollars*.

Large as these figures are, they shrink to small proportions relatively to the world's expenditure on military aviation. From near the very beginning, after a few years of hesitancy and sometimes active opposition from military and naval quarters, aviation, because of its frightful possibilities for war purposes, has been the foster-child of Governments the world over. By 1913 the expenditure by Governments had reached a total of nearly $90 million (global), with the result that on the outbreak of the First World War, aircraft industries were already in being, and shortly afterwards were being expanded at a great rate.

The belated but effective interest that the Great Powers put into military aviation soon began to influence the conduct of the First World War, first in reconnaissance, artillery observation and in the use of fighting aircraft to prevent the enemy from doing the same thing, and soon after, the bombing of military and naval targets on a considerable scale. Multi-engined bombers made their first

*U.S. billions—1,000 millions.

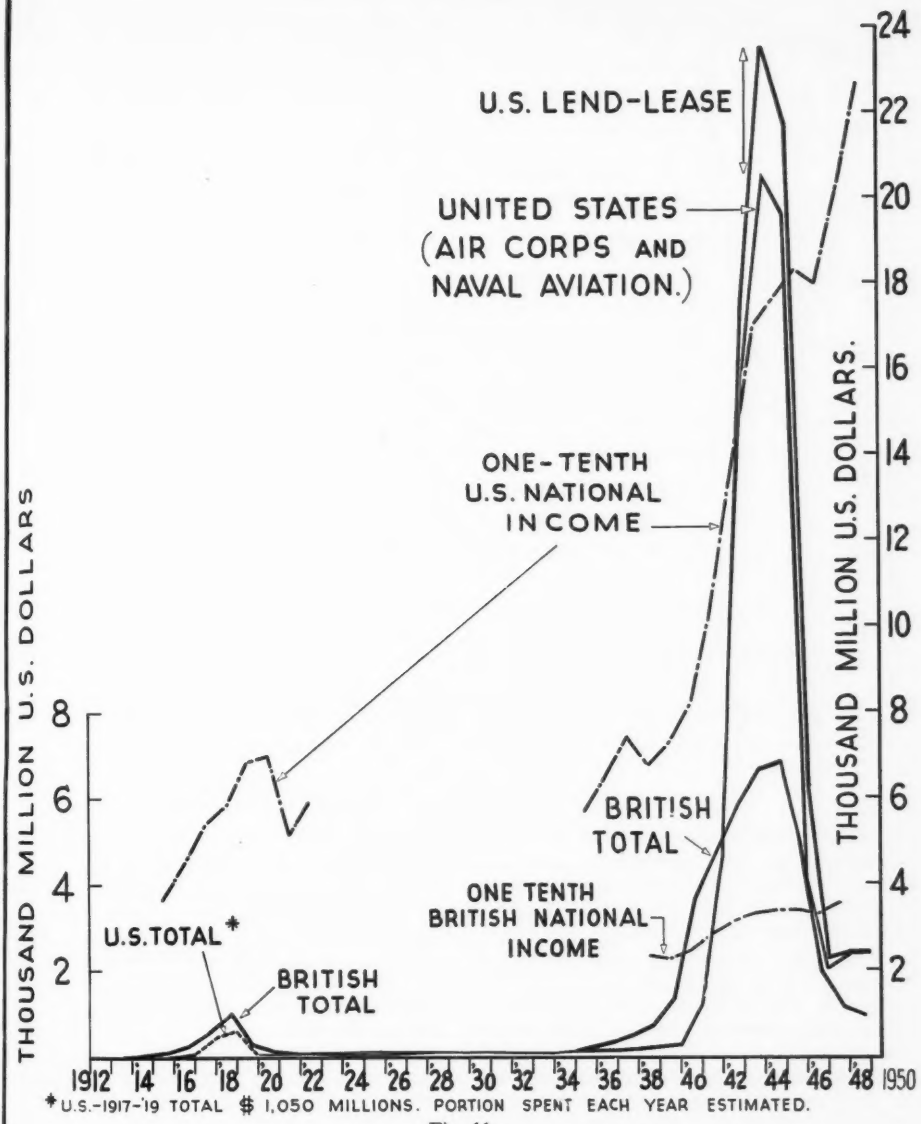


Fig. 11.
Expenditure on Military Aviation. Britain and the United States.

appearance and with them the beginnings of strategic bombing.

It is of interest to examine and compare the military expenditure of the Great Powers and to consider some of the factors that were responsible for its variations during and between the Wars (Figs. 11 and 12). With a few exceptions the figures for nearly all countries show a similar trend—a rapid rise after the first war had begun, to figures that, while negligible in relation to that of the second war, did mean aeroplanes by the thousand. (Aviation accounted for 4 per cent of the total war expenditure.) Then a

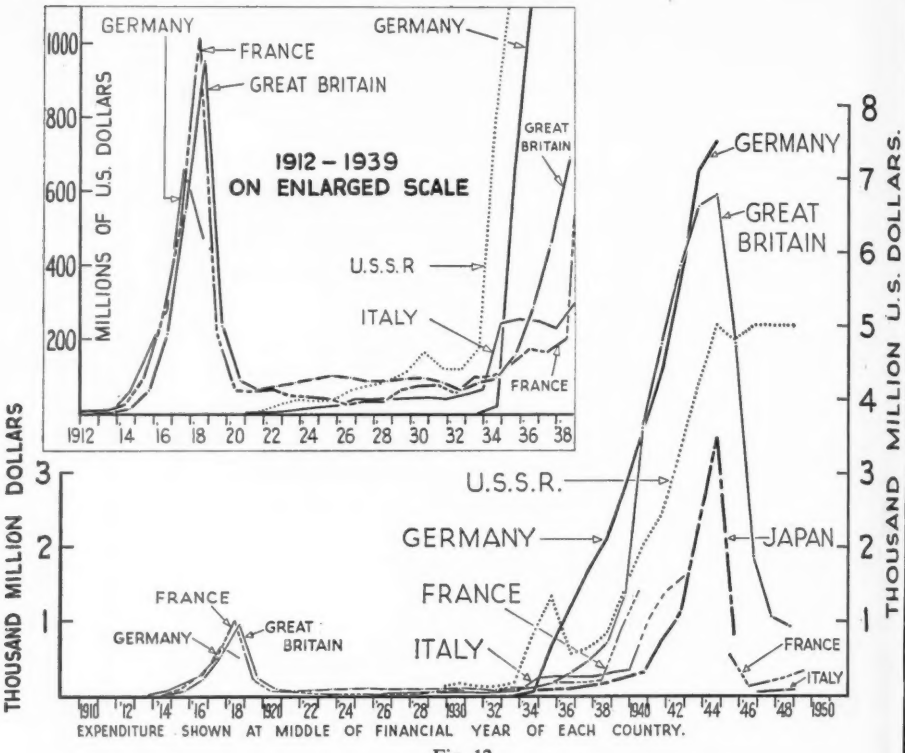


Fig. 12.
Expenditure on Military Aviation. European Powers and Japan.

falling back to nearly a dead level that hardly changed for a period of 15 years. The curves rise scarcely perceptibly until the onset of the Second World War threw its shadow before it.

The absence of reliable Russian statistics introduces the biggest element of possible error in the estimate of world military aviation expenditure that I am endeavouring to present, as compared with the precise Governmental statistics from which the bulk of it is computed. The Russian figures are submitted with every reserve, being frankly broad estimates based on very little data.

The Russians publish their total defence vote, but no allocation as between Services. I have some interesting figures on aircraft production placed at my disposal by Mr. Postnikow, and these check well with Mr. Asher Lee's deductions and the United Nations' Summary of Annual Expenditure. Nevertheless, cross-checking by varying methods yields results that are not easy to reconcile.

It is reasonable to assume that in view of the relative labour rates Russian aircraft are much cheaper than those of the Western Powers and that, to a considerable extent, bridges the gap between their apparent production and front-line strength and the ostensible expenditure. It is further permissible to assume that the percentage of their total defence expenditure allocated to aviation will have risen since the War, in view of the reduction of military activity and their concentration on the Air Arm.

Between the Wars Russian annual expenditure (Figs. 12 and 13) rose slowly and by 1933 (that critical year) had reached a figure of less than 200 million dollars, and then in common with the German, and indeed before them, it started to rise steeply. The apparent fall in 1936 is again a fault of the monetary yardstick and is due to devaluation of the

rouble. It resumed its rapid rise, however, and by the outbreak of the War had almost reached 1½ billion dollars, equal to the British but by then away behind the German.

Wartime expenditure continued to increase and would appear to have been remarkably little affected by the invasion. It is known that the Russians received a total of 20,570 aircraft from their American and British allies. Like the Germans, they never achieved a strategic bombing force. Of Naval aircraft they had but a few.

From 1944 onwards the absence of figures and the difficulties of estimate are even more marked. Estimates of the percentage of defence in the total budget fall progressively from 52 per cent. to 23 per cent., although the proportion of air defence out of that may well be rising. There appears to be quite a consensus of informed opinion that Russian output today, coupled with that of her satellites, is in the order of at least 25,000 and possibly 40,000 aircraft per annum, of which a large proportion are jet fighters and bombers of the Tu.70 type.

As against the dangers of under-estimation of Russian military preparations can be set the formidable task of maintaining on an operational basis some 15 air armies of say, 1,000 aircraft an army, which, according to Asher Lee, would be the operational equivalent of that production, together with the absorption of storage of an output of 40,000 aircraft per annum. Without casualties at a war rate the accumulation, surely, would soon become unmanageable. Between these various estimates I find little option but to submit that the only approximation I can offer of Russian expenditure from the end of the Second World War to the present day is that it has remained substantially level at nearly its highest figure, as compared with the rapid drop of the Western Powers. Study of the available information induces the feeling that this may well be an under-estimate.

The Italian figure during the first war and a period thereafter is estimated as being considerably lower than the other Powers, but takes a steep rise also in 1933, possibly because of the Abyssinian War and general Fascist ambitions (Fig. 12).

France, whose expenditure in the First World War topped any other Power, falls off at a level which equalled Great Britain for two or three years, and then drops below it. As with the civil, the trend of French

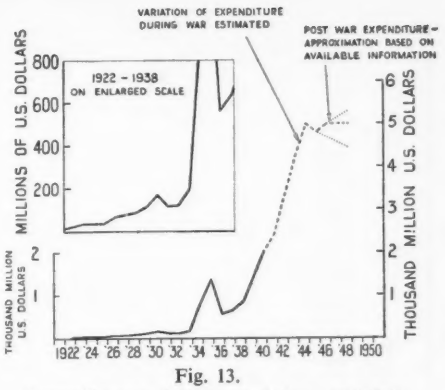


Fig. 13.
Expenditure on Military Aviation. U.S.S.R.

military aviation is considerably affected by variations in the exchange rate. In common with most other Powers, their expenditure shows the slump of 1930-32 and their production was not helped by the nationalisation which was forced on the Industry later. Some firms were returned to free enterprise before the Second World War, but too late to affect any serious recovery.

The figures for the smaller European countries show in their due proportion the same general level up to 1932, when Poland started an increase that was to multiply its expenditure eight-fold within seven years. Later the Netherlands did the same in much quicker time and since the Second World War have continued to expand, as has also Belgium. A dominant feature is the high expenditure of Sweden which increased greatly its expenditure during the War, and afterwards, to a peak of 70 million dollars (Fig. 14).

Of the European curves the German is the most interesting and ominous (Fig. 12). After the First World War military aviation was forbidden altogether, and other aviation activities were restricted by limitation of horse power and other means. In 1926 the Control Commission was withdrawn (albeit that had been ignored to an increasing extent for two years previously). No military expenditure is recorded until 1934 when they made an appropriation of $20 million for air defence. Nevertheless, their other expenditure covered (both deliberately and otherwise) much military preparation.

Under the Weimar Republic considerable capital had been put into production plant,

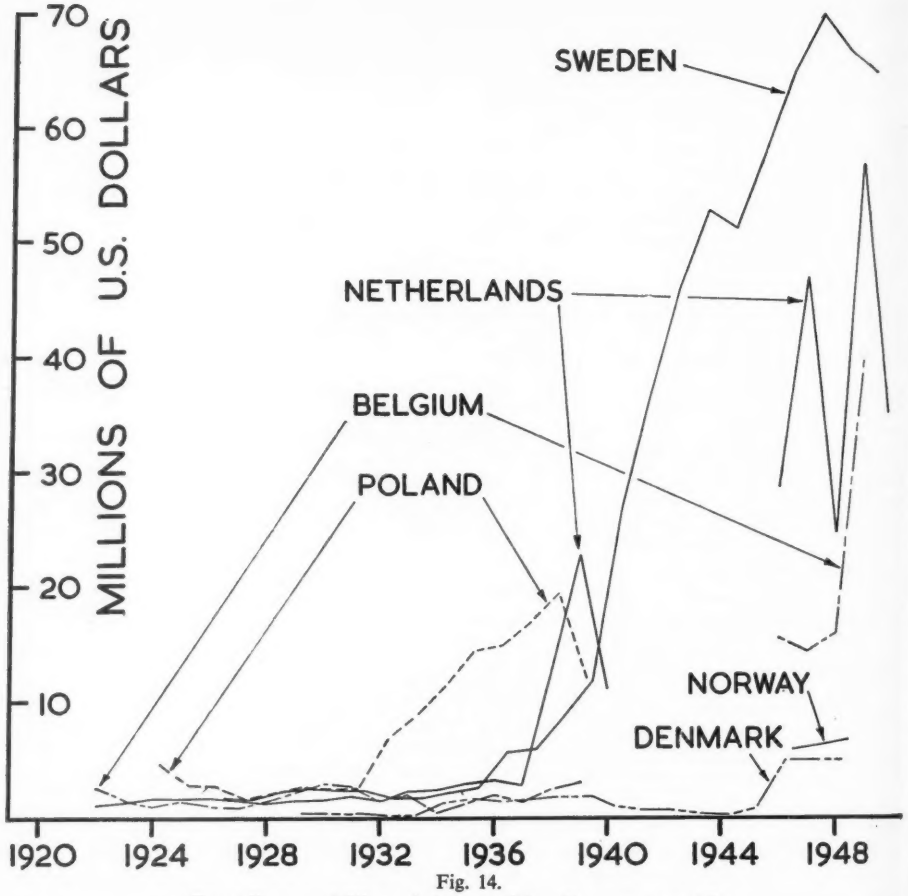


Fig. 14.
Expenditure on Military Aviation. Other European countries.

raw material fabrication and like activities, things which were not forbidden by the Treaty of Versailles. Moreover, the Germans had taken to building alleged civil aircraft easily converted in factories abroad for Military purposes, together with other devices. For example, the Dornier Company had tactfully erected another factory on the Swiss side of Lake Constance, where Allied restrictions had no force. The Junkers Company had a plant in Sweden building two-seater fighters, and Rohrbach one in Denmark. The Hitler Government certainly inherited a considerable amount of preparation from its predecessors, which they exploited to the full. Hitler had a further stroke of luck. His accession to power coincided with the emergence of the all-metal stressed-skin monoplane which was destined to become the standard type. He was able to draw up his plans at a period of great aerodynamic advance, and unhampered by any back-log of older material.

In the first year of the National Socialist movement the total German expenditure was multiplied nearly three-fold and in a further year trebled again, and continued to rise at an awe-inspiring rate. In the financial year 1938-39 the Supply Estimates had reached 1½ billion dollars and 2·4 billion dollars was planned for 1939-40. The German Government thought, and indeed Goering proclaimed, that they had made for themselves such a start that no Power ever could

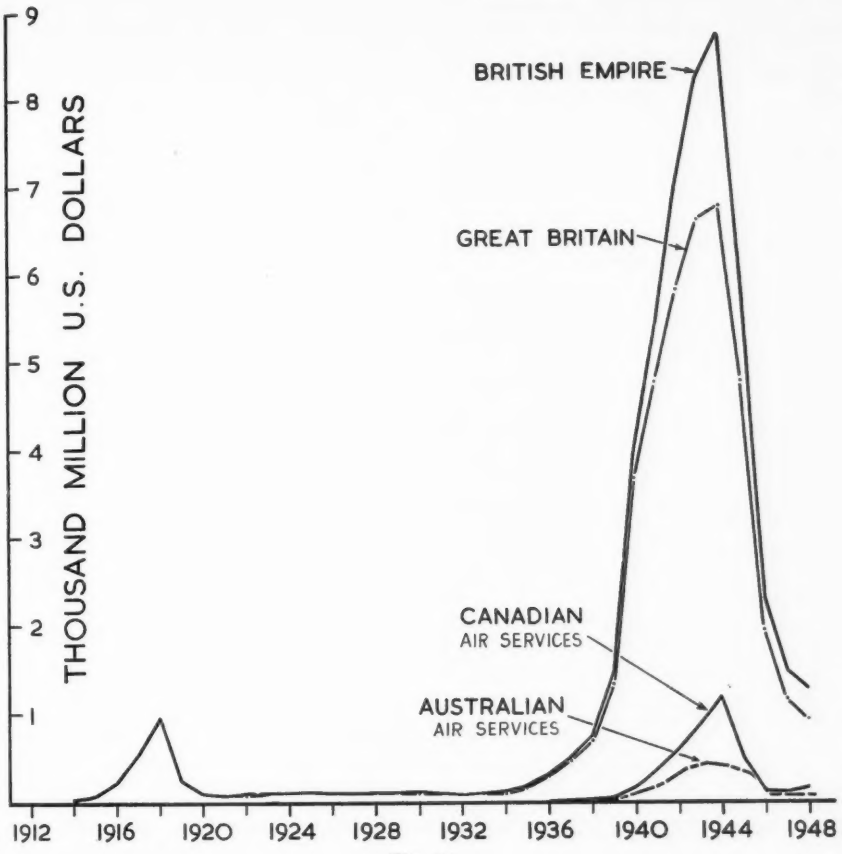


Fig. 15.
Expenditure on Military Aviation. British Empire.

overtake them. That indeed was a misjudgment of the first order and one that, coupled with their failure to appreciate the possibilities of British response, or the tremendous potential of the United States production, ultimately cost them the War.

The entire German air effort, conceived on a basis that was thought to be overwhelming, dominates the picture for the next few years. The expenditure reached its peak in 1944 at 7½ billion dollars when it was cut down by the bombing of the Allied Air Forces. Despite the broad scope of its beginnings and the grandiosity of its planning, it suffered in War years from indecision and erratic change, together with the diversion of resources to the production of guided weapons. Had that effort been devoted to the production of jet fighters, which they were already building in small numbers, the story of the bombing of Germany might have been quite different.

The response of the more peaceful Powers was doubtless delayed by sheer unbelief that a new and worse war was deliberately in the making, but nevertheless there is no question as to its effectiveness.

The British and American graphs (Fig. 11) are very alike in general pattern and still more so in regard to the relative population and proportion of national income expended. Up to and during the First World War the British figures exceeded the American, and in the interim there is little between them. The real expansion starts with the British

some five years before the American and remains above it until 1941-42 when the uprush of American expenditure carries it through and far beyond. Actually in terms of proportion of national income, the British is the greater effort.

The British expansion from 1936 onwards is noteworthy and what would have been the effect had it been two or three years earlier is a question of considerable interest. The rate of increase in 1938 paralleled the German, and in the next year exceeded it. This expenditure was not to be reflected in numbers of aeroplanes for a year or more—even in 1938 the shortage of modern aircraft was extreme—but by 1939 the Royal Air Force was in a position to send sufficient squadrons to France to match the British Expeditionary Force, while retaining the Home Defence Forces in England, and in one more year, although outnumbered 4 or 5 to one, to defeat the Luftwaffe in pitched battle. Within two more years it was to launch 1,000-bomber raids on Germany.

Moreover, the period of greatest expansion, including the hectic struggle to build up the fighter force after Dunkirk, when invasion seemed imminent, was carried on under bombing and blackout, and other concomitants of aerial and submarine warfare. It was during that time that the four-engined bomber production was organised, and new types in nearly every category, including jet fighters, were planned for production. At its peak, expenditure reached 6¾ billion dollars, or one-fifth of the national income.

Despite their relatively small populations both Canada and Australia achieved during the War remarkably large production of aircraft, as well as maintaining highly efficient air forces (Fig. 15).

As we have noted, the first real increase in American Military aviation expenditure started in 1940 and with incredible rapidity reached a rate of expansion and a peak of expenditure unequalled in degree by any other Power and at its height nearly equal to that of all the other belligerents combined. From just over a billion dollars in 1941 it had caught up with the British and German figures in 1942 at 5 billions, and by 1944 had reached its peak at 23½ billion dollars, or 13 per cent. of the steeply rising national income (Fig. 11).

Contemporarily with this rapid expansion the American Aircraft Industry was to introduce a great number of new types, including its prodigious programme of heavy bombers, to be followed by the super-heavies for use against Japan. It had to keep pace with innumerable modifications, dictated by the changing requirements of the battle fronts, including such items as bomb stowage, armament, and crew arrangement, and yet simultaneously to achieve a large measure of standardisation with the British. It was to produce four-engined bombers more than twice the weight of the largest pre-War types, and bring out type after type of fighter with ever-increasing performance.

It was an industrial achievement unrivalled even proportionately throughout history. It involved the rapid creation of huge plants, many of four million square feet and employing some 45,000 workers, backed by raw material production and fabrication, together with resources for the production of engines, instruments, equipment and armament on a proportionate scale, and the training of the requisite male and female labour for precision production. Once well under way production ran to schedule or exceeded programmes that had been thought to be hopelessly optimistic when first drawn up.

The German Air Force and building programme had been conceived and prepared to form the spearhead of the weapon that was to conquer first Europe, and then the world. Theirs was the choice of weapons and yet early in the War it could not prevail over the Royal Air Force. By 1943 the American and British strategic bombing forces were pounding Germany to pieces. One is inclined to wonder at what period it dawned on the German mind that the possibilities of Anglo-Saxon aircraft production and operation had been underestimated.

Of the remaining belligerents, the Japanese figures are of interest. In total expenditure it is smaller than one would have expected from their initial, although short-lived successes, particularly against shipping, nor was any proportionate devotion to aviation displayed in their invasion of China, which had been in progress for several years. Their peak expenditure is estimated to have been 3½ billion dollars in 1944, followed by a sharp decline, and their total throughout the War 8 billion dollars. Despite a few technological and indeed psychological surprises (the Kamikaze bomber could hardly have been conceived by other than the

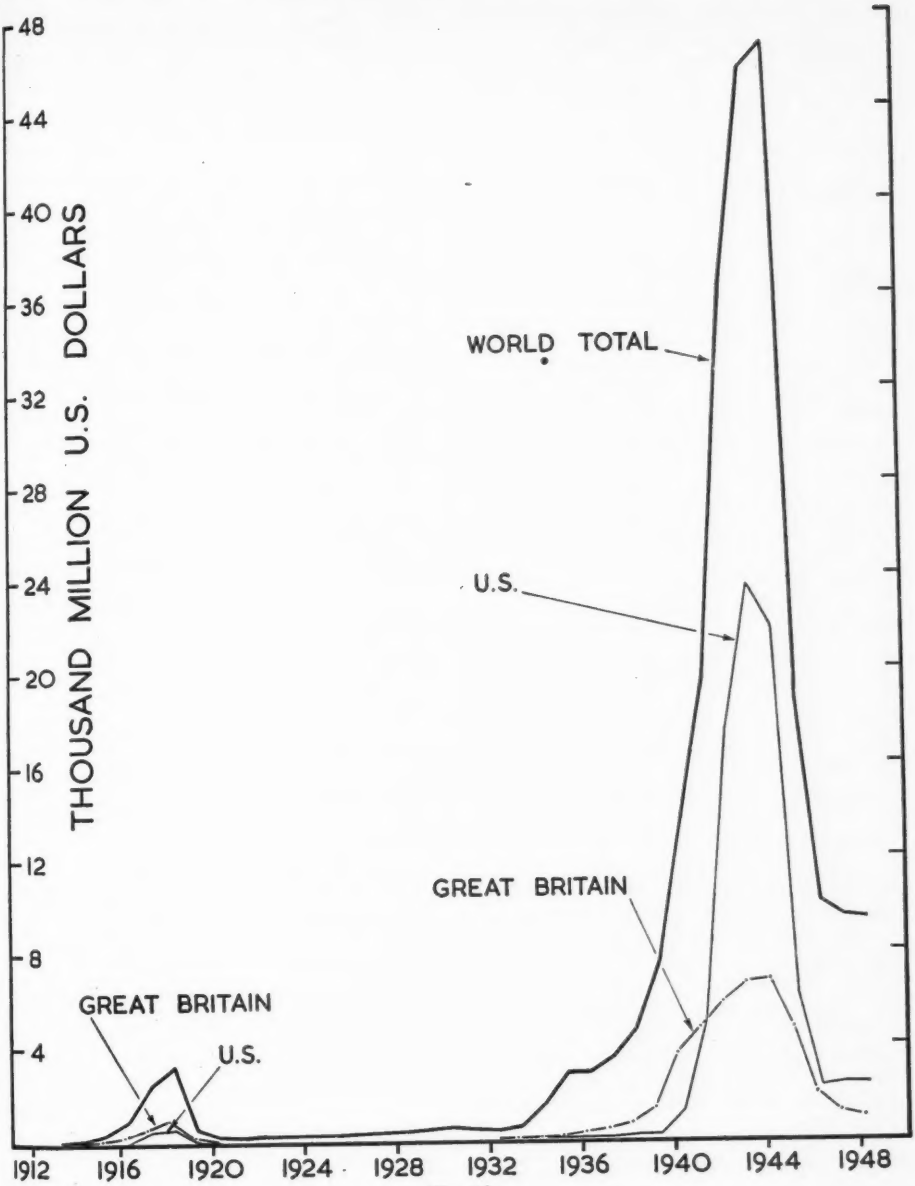


Fig. 16.
World expenditure on Military Aviation.

oriental mind) they were soon overwhelmed by the might of American aviation.

Outside the Great Powers nearly every civilised nation in the world incurred expenditure on military aviation, some from the very outset, but in amounts that are of a very small order by comparison (Fig. 14). Nevertheless, they have been computed and added to make up the world totals which I now submit.

Figure 16 gives these aggregate figures and displays the same characteristics that have marked its major components. Its chief interest lies in the grim sum total that it reveals.

We see a rate of expenditure of over 100 million dollars in 1914-15 and a peak of 3 billion dollars during the First World War; then at between 250 and 500 million dollars, rising only slowly for the next 13 years, and then the rise that followed Germany's rearmament. During the Second World War it reached a peak of nearly 47 billion dollars, and since has fallen only to 9 billion dollars, or three times the first war maximum.

It is interesting to integrate the totals over these periods. We find that the world had spent over 100 million dollars up to 1914; and 7 billion dollars during the First World War. From 1918 to 1939 the total was 21 billion. For the Second World War we arrive at the truly fearsome figure of 188 billions, and a world grand total of money spent on military aviation of no less than 245 billion dollars up to 1949.

What to set against this vast expenditure is a question for the philosopher—or history. That low level line representing the Military expenditure that had been thought adequate by the United States and the United Kingdom, together with the other peace-seeking Powers, through a decade and a half after the first war, and which lifted so reluctantly in response to the threatening German expansion, amounts to a small sum indeed in terms of national income for those countries to set aside for insurance against another war.

One cannot escape the reflection that had it been greater, and had the Governments concerned listened more carefully to such people as Mr. Churchill or General Mitchell, and others who advocated so urgently a higher state of preparation in the air, who appreciated so much more clearly the influence that Aviation was to have in the next War, then indeed that War need never have occurred, and that huge expenditure of 188 billion dollars would not have been necessary. For a fraction of it the whole thing might have been avoided. On the other hand, vast as it is, who can say, in view of the outcome, that it was not money well spent.

Having got so far I was unable to resist the temptation to submit the grand totals of world expenditure on Aviation to date, while again reminding you that I have been forced to bridge the gaps in the records by estimates, some of which introduce considerable possible margins of error. The biggest of these is the Russian, for reasons I have explained, and there are others, for example the Italian record is missing before 1922 and after 1940. The saving grace, as I indicated before, is that the later the period and the larger the outlay, the better is the record.

Apart from the income side of Civil Aviation there is much on the other side of the balance sheet to set against the astronomical figures of expenditure, but the benefits mostly are imponderables. Still less would it be possible to form any reasonable estimate of the vast damage done by military aircraft, or to balance it against the good that has been achieved in the defence of the free countries.

The graph depicting the totals takes the general shape with which we are now familiar (Fig. 17). It displays the over-riding influence of the Second World War and the additional spur that it gave to Civil Aviation since. The others plotted with it reveal how great a proportion of the world total is due to the United States, and the British contribution is not insignificant, particularly when considered in proportion to the population and national income. Its main interest, however, lies in the gigantic totals that it reveals, and which give at least some proportionate idea of the amount of human effort that has been devoted to the cause of Aviation from its humble beginnings 47 years ago.

From the relatively negligible figure of the earliest years, and the spurt of the First World War, we see only a slow rise from 250 million dollars in 1920 to over 750 millions in the critical year of 1933-34, and then the rapid rise to nearly 8 billion dollars at the outbreak of the last war. Within four years it has leapt nearly sixfold to 46 billions, adding another billion in the next year, before it falls even faster than it had risen. By the end of the period under review world

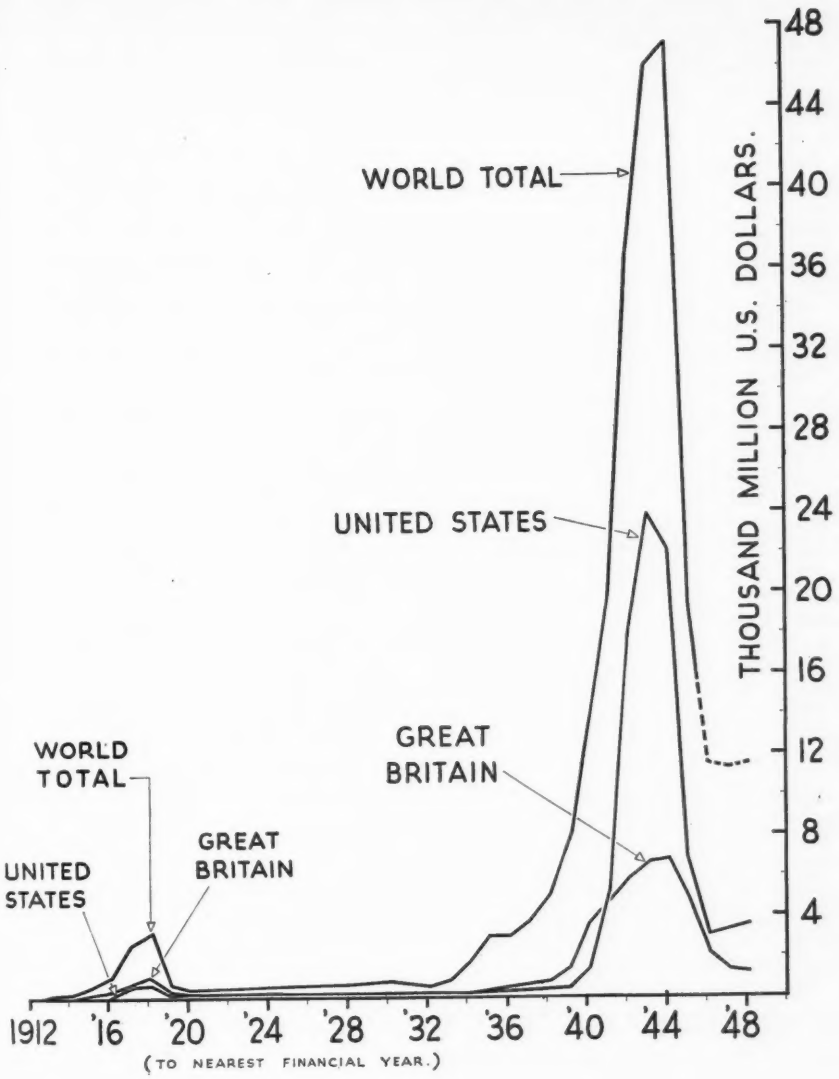


Fig. 17.
World expenditure on aviation.

total expenditure on Aviation had dropped to 11 billion dollars, and now again it has started to rise.

The integration of these vast figures of annual expenditure is a question only of arithmetic and still with the reservation with regard to the margin of error that I emphasised at the beginning, I submit the figure of 256 thousand million dollars as the total expenditure that has been incurred up to less than a year ago, since the Wright brothers made their great contribution towards this

latest and greatest of human material achievement in motion. All of which goes to show how considerable the consequences may be when scientifically-minded engineers set out to explore a new realm in physical conquest.

I have many acknowledgments to make:—first, to Mr. Gerald Lyon, an Associate Fellow of the Society, for his arduous and able work in collecting and converting statistics, which has involved much harassing of Embassies and Government Departments, and many thousands of miles of air travel.

While taking to myself all responsibility for the interpretation and deductions from the information made available, I wish to express my sincere thanks for the help given by the Air Ministry Library and Information Division, the Ministry of Civil Aviation, the Admiralty and the Ministry of Supply.

For records of American aviation I am particularly indebted to Mr. F. B. Lee, Assistant Administrator of Civil Aeronautics, and his staff; to the Aeronautics Division of the Library of Congress where, by special permission of Mr. Orville Wright's executor, access was given to the Wright brothers' papers deposited there last year; and to Mr. Fred C. Kelly.

I am indebted for many figures which have been incorporated to the Navy Department and the United States Air Force authorities in Washington, and to the Air Attaché, Naval Attaché for Air and Civil Air Attaché at the American Embassy in London.

My thanks likewise are due to the Air Liaison Officers in London of the Dominions, and to the Air Attachés in London of Sweden, Denmark, Norway, France, Italy; to the Belgian and Netherlands authorities, Arsenal de l'Aéronautique, Air Commodore Rayski formerly of the Polish Air Force, and to Mr. A. A. Postnikow; to Air France, Koninklije Luchtvaart Maatschappij (Royal Dutch Airlines), Société Anonyme Belge d'Exploitation de la Navigation Aérienne, Scandinavian Airlines System, Swiss Air Transport Company, Pan-American Airlines, Transcontinental and Western Air Incorporated, and British Overseas Airways Corporation; also to the Institute of International Affairs and Institut Francais du Transport Aérien.

Information regarding particular types of aircraft has been kindly supplied by Lord Brabazon, Sir Francis McClean, Sir Geoffrey de Havilland, Sir Alliott Verdon-Roe, Mr. Glenn Martin, Mr. Oswald Short, Mr. Robert Blackburn, the Bristol Aeroplane Company Limited, Douglas Aircraft Company, Incorporated, and Boeing Airplane Company.

I wish to acknowledge the courtesy of the writers or publishers of the following works from which statistics have been used:—

"The Struggle for Airways in Latin America." William A. M. Burden.

"The Soviet Air Force." Asher Lee, O.B.E. (Duckworth.)

"Japan's Economy in War and Reconstruction." Jerome B. Cohen. (Minnesota University Press.)

"World Aviation Annual 1948." Edited by J. Parker van Zandt.

"Aviation Facts and Figures." Edited by Dr. Rudolf Modley. (Copyright McGraw-Hill Company.)

International Civil Aviation Organisation Statistical Summary.

Reports on the Progress of Civil Aviation. H.M. Stationery Office.

Appropriation Accounts. H.M. Stationery Office.

Civil Aviation in Canada. Dominion Bureau of Statistics.

"Silver Jubilee of the Royal Canadian Air Force."

C.A.A. Statistical Handbook of Civil Aviation. U.S. Department of Commerce.

U.S. Civil Aeronautics Board Annual Reports. Combined Statements of Receipts, Expenditures and Balances of the U.S. Government.

Reports to Congress on Lend-Lease.

Flight 1909-1914.

Other sources of statistics are gratefully acknowledged on the charts concerned.

The President: By tradition, the Wilbur Wright Memorial Lecture was not followed by a discussion; the more formal proceeding of the proposal and seconding of a vote of thanks took its place.

He had invited for those duties two Past-Presidents of the Royal Aeronautical Society—Sir John S. Buchanan (Immediate Past-President) and Lord Brabazon of Tara—both of whom had been closely associated with the Lecturer in one way or another for many years.

A special welcome awaited Sir John, mixed with regret because he had just vacated the Presidential Chair; the occasion provided an opportunity of thanking him for his untiring work during his term of office.

To Lord Brabazon, as President of the Royal Institution, an expression of grateful thanks was due for having allowed the Society to occupy the theatre for the Lecture.

Sir John S. Buchanan: It was not often that one had the opportunity to say "Thank you" with so much conviction and personal understanding. For many years he had followed the work of Sir Richard and had been his most constant admirer.

It was well known that Sir Richard Fairey was one of the chief architects of British aviation, with which he had been concerned for practically the whole of his engineering life. Aviation had attracted him early in his career and in 1911 he was the General Manager of the Blair Atholl Aeroplane Syndicate developing the Dunne aeroplane. In 1913 he became Chief Engineer to Short Brothers and soon after the outbreak of World War I, founded the Fairey Aviation Company.

His pioneer work on the development of wing flaps for the reduction of landing speed added an important chapter to the history of aviation in Great Britain and, it was only too frequently forgotten. Under his direction there had emerged a continuous succession of first-class successful aeroplanes, beginning with the "IIID" and "IIIF"; followed by the "Flycatcher" and the "Fox," the long-range aeroplanes, the "Seal" and the "Firefly," to name only a few. He had realised at an early stage the limitations of the float seaplane for naval duties, and had directed his attention to the development of the deck-landing aeroplane. From subsequent events, it would appear that, although he gave up seaplanes, he found himself unable to forsake the sea altogether and took to yachting in order to balance his basic versatile mentality.

He had the rare capacity of combining theory with practice and, as was only too clear from his lecture, he possessed a well-balanced understanding of their financial implications.

Sir Richard Fairey was President of the Society of British Aircraft Constructors from 1922 to 1924, and President of the Royal Aeronautical Society from 1930 to 1934. This Society owed him a great debt of gratitude not only for the enthusiasm he had infused into its development, but also for his personal generosity.

Lord Brabazon of Tara seconded the vote of thanks: As President of the Royal Institution he was proud to welcome the Royal Aeronautical Society for the delivery of the Wilbur Wright Memorial Lecture. The Society had themselves honoured the Institution by its presence on such an important occasion in the affairs of aviation, and he hoped that the Lecture would always be given there.

He seconded the vote of thanks to his old friend, Sir Richard Fairey, with much enthusiasm and sincerity. He had been in constant touch with that very great man, great physically and mentally, since the days of Eastchurch—which now seemed to have been about the time of the Norman Conquest!

He was glad that there had been so many interesting slides accompanying the Lecture and, because he had been indirectly responsible for the spending of more of the taxpayers' money upon one machine than had anyone else, he had noted with relief that the period of time covering the expenses incurred in aviation, as illustrated by the slides, had come to an end before his own particular bill had been presented!

It was indeed novel to feel that, although for a number of years the efforts of those engaged in aeronautics had been concentrated upon getting up into the air, the Lecture was the first he could remember which had attempted to get them back to earth!

It was with very great pleasure indeed that he seconded the vote of thanks to such an old friend.

Following the Lecture the Annual Council Dinner was held at 4 Hamilton Place, at which the following were present:—

Robert Blackburn, Esq., O.B.E., M.I.Mech.E., A.M.Inst.C.E., Honorary Fellow (1950); Sir John S. Buchanan, C.B.E., F.R.Ae.S., President 1949-50; Major G. P. Bulman, C.B.E., B.Sc, F.R.Ae.S., President of the Society; J. P. Bulman, Esq, B.Sc.(Eng.); Lord Brabazon of Tara, M.C., Hon.F.R.Ae.S., President 1934-36.

S. Camm, Esq., C.B.E., F.R.Ae.S., Vice-President; A. V. Cleaver, Esq., F.R.Ae.S., Council Member; Air Chief Marshal The Hon. Sir Ralph Cochrane, K.C.B., K.B.E., A.F.C., A.D.C., Vice Chief of the Air Staff; Air Marshal Sir W. Alec Coryton, K.B.E., K.C.B., M.V.O., D.F.C., Controller of Supplies (Air), Ministry of Supply; Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., President 1947-49.

Colonel W. C. Devereux, C.B.E., F.R.Ae.S.; Dr. S. F. Dorey, C.B.E., F.R.S., President, Institution of Mechanical Engineers; Dr. G. P. Douglas, O.B.E., M.C., F.R.Ae.S., Council Member.

G. R. Edwards, Esq., M.B.E., B.Sc., F.R.Ae.S., Vice-President; A. G. Elliott, Esq., C.B.E., F.R.Ae.S., Council Member; Air Marshal Sir Basil Embry, K.B.E., C.B., D.S.O., D.F.C., A.F.C., Air Officer Commanding-in-Chief, Fighter Command.

Sir Richard Fairey, M.B.E., Hon.F.R.Ae.S., Wilbur Wright Lecturer, 1950, President 1930-34; W. S. Farren, Esq., C.B., M.B.E., M.A., F.R.S., F.R.Ae.S., Council Member; Sir A. H. Roy Fedden, M.B.E., D.Sc., F.R.Ae.S., President 1938-40, 1944-45.

Sir Arthur Gouge, B.Sc., F.R.Ae.S., President 1942-44.

Major F. B. Halford, C.B.E., F.R.Ae.S., Vice-President; Lt. Colonel Leonard R. Hall, Assistant Air Attaché, U.S. Embassy; S. Scott Hall, Esq., C.B., M.Sc., D.I.C., F.R.Ae.S., Council Member; Neilson J. Hancock, Esq., A.F.R.Ae.S., Council Member; Sir William Hildred, C.B., O.B.E., M.A., Director-General I.A.T.A.,

Major General Leon W. Johnson, Commanding General 3rd Air Division, United States Air Force; E. T. Jones, O.B.E., M.Eng., F.R.Ae.S., Council Member.

Lord Kenilworth, C.B.E., F.R.Ae.S.

Air Marshal Sir Hugh P. Lloyd, K.B.E., C.B., M.C., D.F.C., Air Officer Commanding-in-Chief, Bomber Command.

Brigadier General Sir H. Osborne Mance, K.B.E., C.B., C.M.G., D.S.O., President, Institute of Transport, Oldest Society Member; P. G. Masefield, Esq., M.A., F.R.Ae.S., Council Member; Sir Francis McClean, A.F.C., Honorary Fellow (1950).

Captain F. O'Beirne, U.S.N., Assistant Naval Attaché and Assistant Naval Attaché for Air; Roland T. Outen, Deputy Chairman, Fairey Aviation Company.

Sir Frederick Handley Page, C.B.E., Hon.F.R.Ae.S., President 1945-47; The Rt. Hon. Lord Pakenham, Minister of Civil Aviation; W. G. A. Perring, Esq., C.B., F.R.Ae.S., Council Member; Major R. A. Powell, A.F.R.Ae.S., President, Southern Africa Division of the Society; Colonel R. L. Preston, C.B.E., A.F.R.Ae.S., Secretary-General, Royal Aero Club; Captain J. Laurence Pritchard, Hon.F.I.Ae.S., Hon.F.R.Ae.S., Secretary to the Society.

Sir H. R. Ricardo, B.A., F.R.S., F.R.Ae.S., Chairman and Technical Director, Ricardo and Co. Ltd.; N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S., Council Member.

Lord Sempill, A.F.C., F.R.Ae.S., President 1927-30; Air Chief Marshal Sir John Slessor, G.C.B., K.C.B., D.S.O., M.C., Chief of the Air Staff; T. O. M. Sopwith, Esq., C.B.E., Honorary Fellow (1950).

C. F. Uwins, Esq., A.F.C., O.B.E., F.R.Ae.S., Honorary Treasurer to the Society.

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FLIGHT REFUELLING AND THE PROBLEM OF RANGE*

by

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INTRODUCTION

The main function of refuelling in flight is to increase the range, or increase the pay-load over long stage lengths.

The quest for range has brought about a steady increase in aircraft size throughout the years and it has now become apparent that a new barrier, the range barrier, is an even more formidable barrier for designers to overcome than that caused by increasing resistance with increasing speed, especially at the speed of sound.

Figure 1 shows the weight of record-holding aircraft plotted against distance, from the first flight, of 284 yards, by Orville Wright in 1903. By 1909 Bleriot heroically struggled across the English Channel, a distance of 22 miles, and this was followed in later years by the Atlantic conquest by Alcock and Brown in 1919, Lindbergh's solo Atlantic crossing of 1927, and so on to the more recent record achievements of the B29 "Pacusan Dreamboat" and the P2V-1 Neptune "Truculent Turtle."

At first the distance was pushed up fairly rapidly with a gradual increase in the size of aircraft, and by 1938 the distance record of 7,162 miles was achieved by the R.A.F. Long-Range Development Unit in their flight from Egypt to Australia with two Vickers Wellesleys, of only 10,000 lb. weight each. Beyond this point, considerable increments in size were necessary in order to bring about relatively small improvements in the record, and after nine to ten thousand miles the quest for greater ranges leads to very big aircraft. Even then the take-off is generally made in a grossly over-loaded state. A number of the records shown in Fig. 1 were made under over-loaded conditions at take-off: for example, the P2V-1 Neptune had a 47 per cent. over-load, and had a fuel load almost as great as its normal take-off weight; the take-off was assisted by rockets, and the ceiling was little more than wave-top for several hundreds of miles.

Thus the designers have provided for each increment of distance by adding first more tankage and then more power and more structure, the additional structure being required not only to carry the additional fuel for lengthening the flight, but also for supporting the additional power required for that extra structure. A vicious spiral in fact.

It is my belief that designers followed this line blindly on the assumption that whenever greater range was required, it could be met by producing a larger aeroplane.

Figure 2 shows curves of fuel load and passenger load plotted as percentages of gross weight, for past and present air liners. Fuel load increased rapidly, with gross weight, from some 10 per cent. and has tended to stabilise at 40 per cent. (or 4/5ths of the disposable load), while passenger load has fallen correspondingly from 30 per cent. to 10 per cent. and has stabilised today at about 100 passengers.

1. THE BASIC PRINCIPLES OF FLIGHT-REFUELLING

1.1. Airline operational efficiency

The value of a transport service between two given termini is measured in ton-miles (or other suitable weight-distance units) per annum, and a plot of ton-miles against

*A Section Lecture (the 799th Lecture to be read before the Society) given on 25th April 1950.
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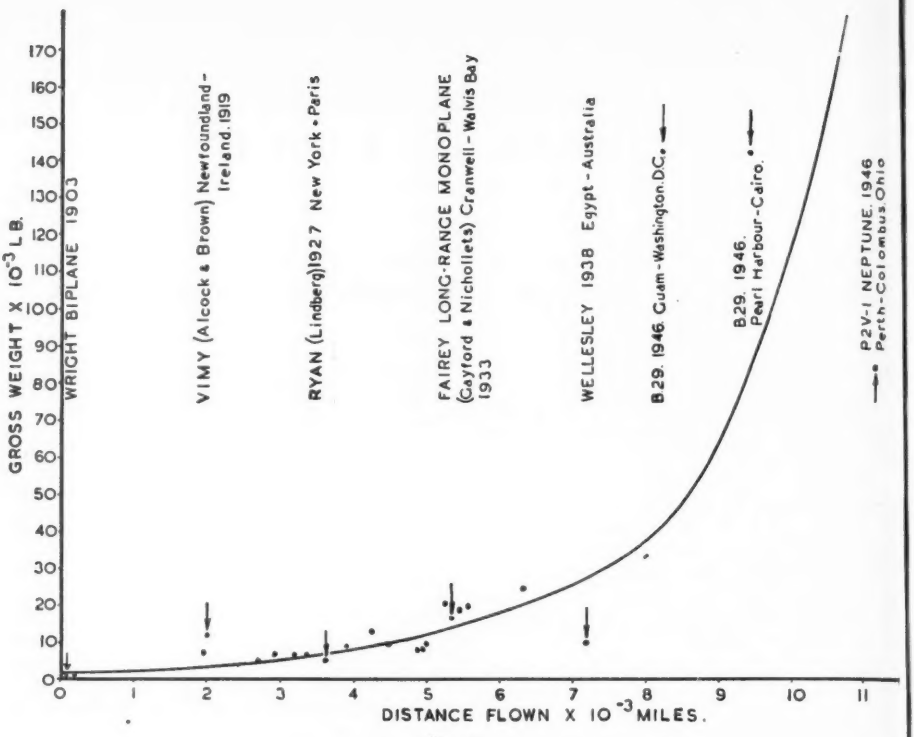
GROSS WEIGHT X 10^{-3} LB.
DISTANCE FLOWN X 10^{-3} MILES.
WRIGHT BIPLANE 1903
VIMY (Alcock & Brown) Newfoundland - Ireland. 1919
RYAN (Lindberg) 1927 New York - Paris
FAIREY LONG-RANGE MONOPLANE (Gayford & Nicholletts) Cranwell - Walvis Bay 1933
WELLESLEY 1938 Egypt - Australia
B29. 1946. Guam - Washington D.C.
B29. 1946. Pearl Harbour - Cairo.
P2V-1 NEPTUNE 1946 Perth - Columbus, Ohio

Fig. 1.
World's distance records, 1903-1950.

distance flown gives a parabola* having its maximum at half the ultimate range, *i.e.* when payload equals fuel load, as shown in Fig. 3.

When considering the effect of flight-refuelling, two extreme cases have to be taken into account:—

(*a*) The over-water route, in which the two termini are situated on opposite seaboards, in which case the tanker must be based on, or close to, the starting terminus, and

(*b*) The over-land route, for which it is assumed that the tanker base may be sited halfway between the termini. This means that refuelling in the air merely takes the place of an intermediate landing by the air liner.

In practice, instances of case (*a*) are likely to arise, but case (*b*) is rather improbable. On the other hand, the majority of long, non-stop air routes are likely to pass over stretches of both land and water, giving compromises between the two extremes, *e.g.* London to Gander, with a suitable location for a tanker station at Shannon.

In case (*a*) it is assumed that refuelling takes place at the optimum point for maximum payload, this being at one-third of the air liner's flight distance. For case (*b*) the tanker is relatively small and in both cases tanker weight increases approximately in direct proportion to increase in the air liner's range.

Payload × Range curves may be drawn for the two flight-refuelled cases considered: the

*It has been assumed that payload versus range is a straight line, *i.e.* fuel consumption a mile remains constant throughout the operational range. This is not strictly correct but is a simplifying assumption that does not materially affect the result at this stage. A mathematical treatment of this aspect is given in the Appendix.

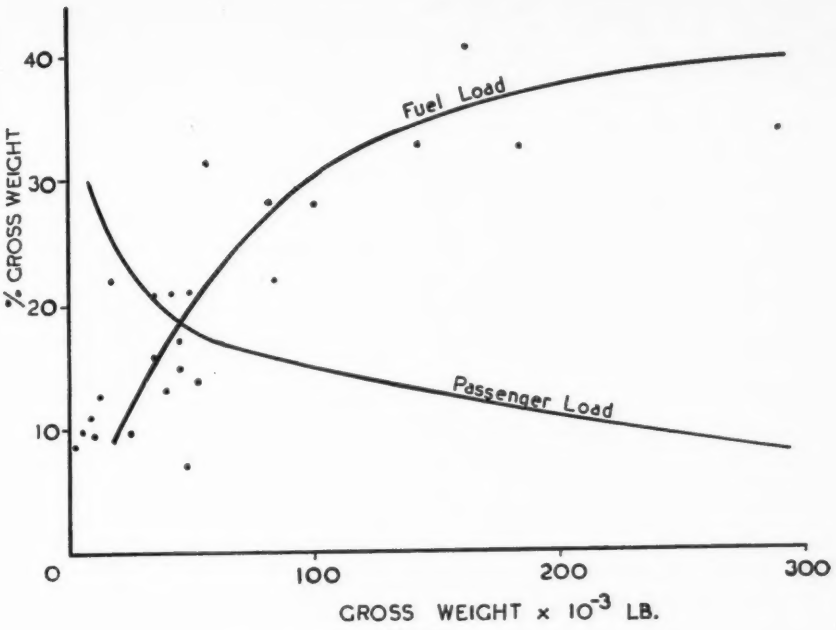

Fig. 2.
Fuel and passenger load versus gross weight.

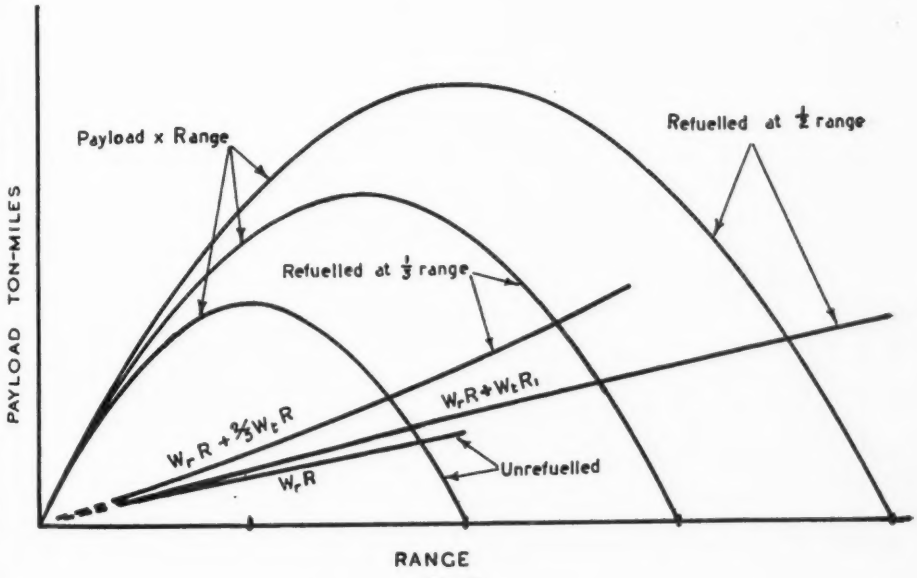

Fig. 3.
Payload ton/miles versus range.

over-water refuelling increases the absolute range by 50 per cent. and the over-land refuelling doubles the range. In both cases, the Payload × Range curves are enlarged as shown in Fig. 3.

One method of indicating the efficiency of an air transport service is to determine the ratio of "output over input," using pay-load ton-miles for the former and air liner flying weight (mean for trip) multiplied by the ultimate range, for the latter. For the flight-refuelled cases the tanker flying weight, times the appropriate value of range, has to be added to the denominator, and in this way comparative efficiency curves on a range base can be obtained, showing the maximum in each case and the increases due to flight-refuelling.

Another method of achieving almost the same result, is to plot both payload ton-miles and aircraft ton-miles on the same range base. The payload ton-mile curves have already been obtained (Fig. 3), and the aircraft ton-miles are found by multiplying mean weight by distance, taking into account the tanker in the flight-refuelled cases.

Masefield* has shown that for long-range operation the revenue from one ton-mile of payload can be taken as £0.28 and similarly

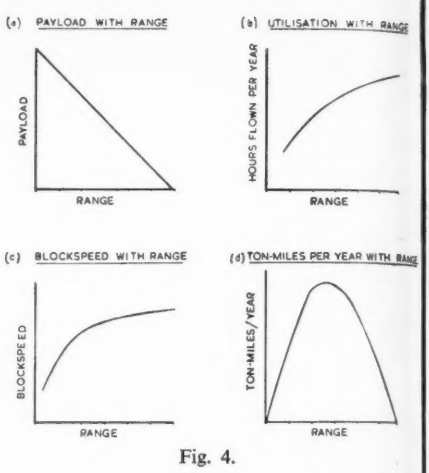

Fig. 4.

the operational cost for ton-miles of an air liner, depending to some extent on annual utilisation and other factors, can be given an average figure of £0.0125, which means that 22 aircraft ton-miles are roughly equivalent to one ton-mile of payload. Therefore in Fig. 3 the aircraft ton-miles have been divided by 22 and the difference between the two sets of curves shows the potential profit.

This diagram provides a good general picture of the beneficial effects of flight-refuelling and not only shows the comparative potential profits for refuelled and unrefuelled services, but also indicates the

*Fourth British Commonwealth and Empire Lecture: Some Economic Factors in Civil Aviation by Peter Masefield, M.A., F.R.Ae.S., M.I.Ae.S. JOURNAL R.Ae.S., October 1948.

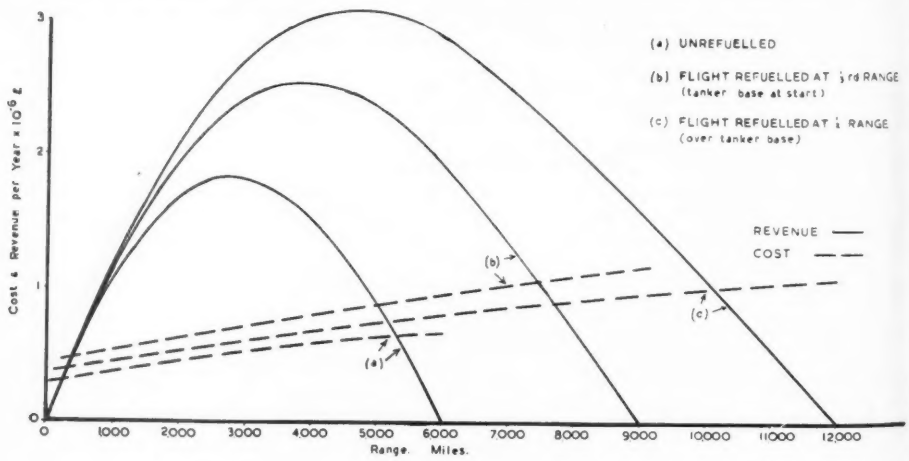

Fig. 5.
Cost and revenue versus range. Flight-refuelled and unrefuelled.

optimum ranges for maximum profits, together with the considerable extension of lucrative range made possible by in-flight refuelling.

Other pertinent factors may now be introduced such as annual utlisation, and variation of average stage speed with range and the aircraft ton-mile curves may be replaced with more accurate operational cost estimates. Fig. 4 shows how the payload ton-mile curve is affected by utilisation and stage speed: the ordinates are now in units of ton-miles per annum and the parabola has become slightly distorted, the maximum now being at approximately 5/12ths of the absolute range.

Figure 5 has been based on an aircraft of 100,000 lb. gross weight, taking all these factors into account. The profit, *i.e.* revenue less cost, has been replotted (Fig. 6) and is for a load factor of 100 per cent., but similar curves can be drawn for any desired load factor and have been added for one of 65 per cent. The diagram has been spotted with one point representing the London-Gander stage of the North Atlantic route. The tanker is stationed some distance along the route and the point therefore lies between the two flight-refuelled curves.

1.2. Relationship of payload to range

The next step is to determine the ultimate theoretical range of long distance aircraft. Fig. 7 has been based upon a number of types, both civil and military, powered by reciprocating engines and jets, assuming zero payload (and accommodation) with all disposable load represented by fuel. This shows that an extreme range of 6,750 miles is a reasonable achievement for passenger aircraft of some 300,000 lb. gross weight, while military aeroplanes are approaching the 8,000 miles mark. The ultimate range decreases with decrease of aircraft weight and is in the neighbourhood of 6,000 miles for a gross weight of 150,000 lb.

The tare weight of air liners is found to be about 50 per cent. of the gross weight, above 80,000 lb., increasing with decrease of gross weight. Fig. 8 shows the division of disposable load between payload and fuel for all ranges from zero to the ultimate, for various gross weights. The weight of passenger accommodation is roughly one-half the weight of passengers. Hence, if an ultimate range of 6,000 miles is assumed for reciprocating-engined aircraft (4,750 for jets), a diagram showing the division of disposable load can be drawn on a range basis. This has been done in Fig. 9, which shows that for the ideal range of 2,700 miles (approximately $5/12 \times 6{,}000$) the fuel weight should be 22.5 per cent. W, the payload 18.25 per cent. W and the accommodation weight 9.25 per cent. W. The diagram has been based

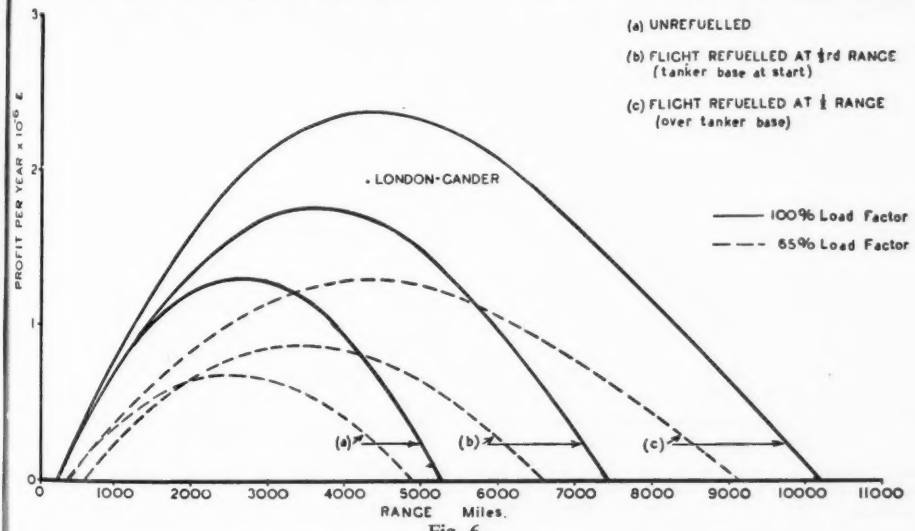

Fig. 6

Profit versus range, flight-refuelled and unrefuelled.

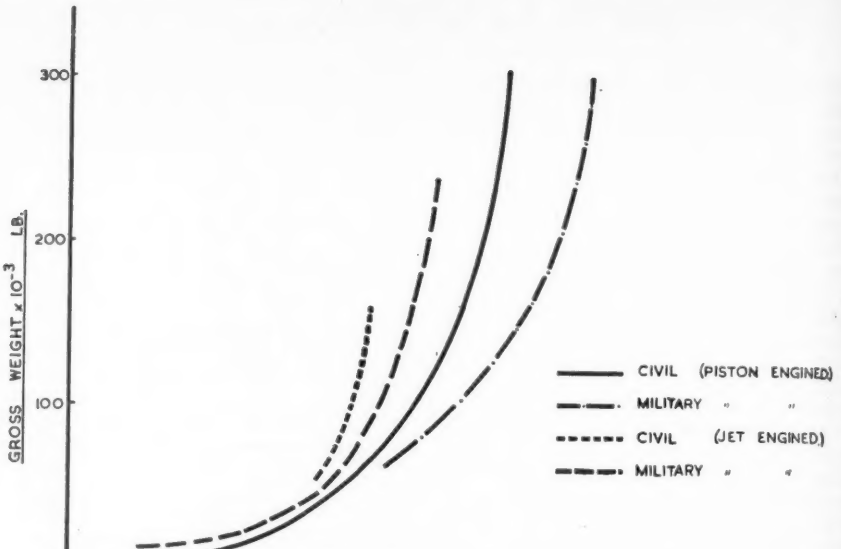

Fig. 7.
Range versus gross weight of piston and jet-engined aircraft.

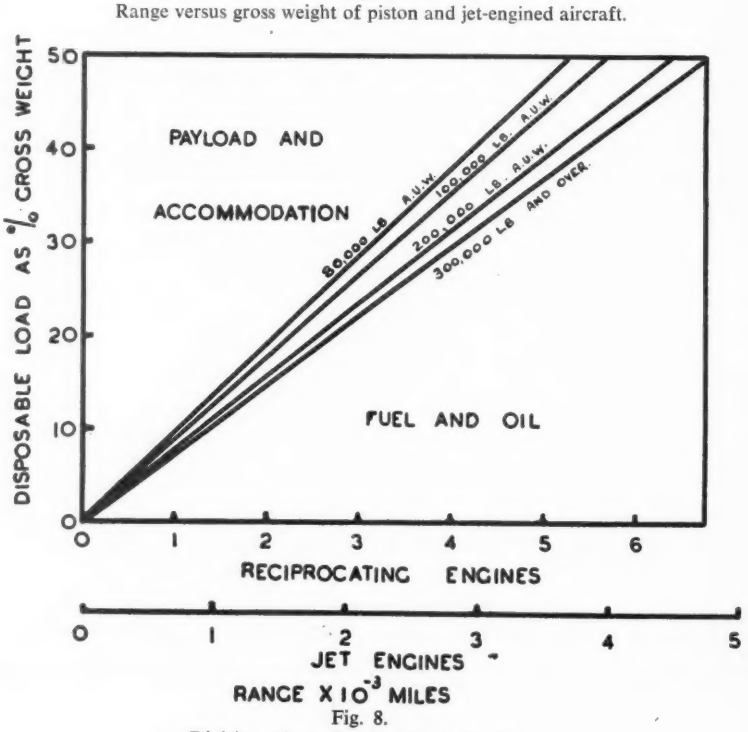

Fig. 8.
Division of air liner's disposable load.

upon certain simplifying assumptions but presents a reasonably true picture and shows at a glance the relationship between payload in terms of gross weight and range in miles for any large civil air liner. The range scale has been given for both reciprocating and jet engines.

The rapid lessening of payload with increase of range is notable and the diagram indicates that for a still-air range of 5,000 miles, unrefuelled, the payload shrinks to less than 6 per cent. *W* and is almost impossible to achieve with jet-propelled liners.

1.3. Optimum still-air range

From Fig. 8 it is seen that for any given range the payload carried for pound of aircraft gross weight tends to increase with gross weight (at least up to 300,000 lb.). The cost of operation for pound of aircraft varies little with size and, if anything, decreases slightly with growth of size, so that, irrespective of route length, operational efficiency is likely to increase with aircraft size. There are other considerations and airline operators have to consider, among other factors, potential traffic and frequency of service.

It has already been shown that for any given aircraft size (weight), there is an optimum range—roughly 0.42 of the ultimate, and for flight-refuelled services between 0.67 and 0.80 times the unassisted ultimate range. Fig. 10 shows the optimum still-air range plotted against aircraft gross weight, both unrefuelled and flight-refuelled.

1.4. Effect of range on aircraft size

If the payload be kept constant, the gross weight, and hence size of an aircraft, increases with increments of range. This is obvious, but the manner in which aircraft size grows with range may not be generally appreciated. Fig. 11, constructed upon the payload percentage of Fig. 9, shows the variation of gross weight with range, assuming a constant payload, the curves being asymptotic. From this it is seen that the rate of increase in size beyond the ideal becomes increasingly steeper. Thus the aircraft (reciprocating engines) of 5,000 miles range designed for the London-New York route, unrefuelled, is three times as large as the ideal air liner.

It is now easy to see how the quest for long range is leading to large-size, uneconomic aircraft. The fact must be faced that a

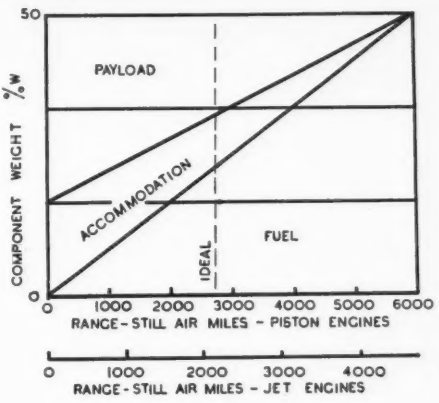

Fig. 9.

Relationship of payload to range for air liners.

radical departure from the ideal arrangement leads inevitably to very big aircraft, which are literally flying petrol tanks.

The similarity between Figs. 11 and 7 is worthy of notice. The former was produced to illustrate the rapid increase in aircraft size with range when keeping the payload of constant amount: no scale of ordinates was given but the "ideal" aeroplane, with a range of roughly half the ultimate, has a payload-plus-accommodation weight equivalent to 25 per cent. of the gross weight. The latter diagram gives the ultimate range of contemporary types of aircraft, when carrying (constant) zero payload or military load.

Figure 12 illustrates the effect of flight-refuelling upon the effort required to transport passengers across the North Atlantic, non-stop, and indicates the growth of weight of flight-refuelled and unrefuelled air liners in terms of passenger payload. From this it is seen that the unrefuelled air liner is twice the size for 25 passengers, increasing to three times the weight of the flight-refuelled aircraft for 150 passengers.

In Fig. 13 the earlier work has been applied specifically to the flight-refuelled North Atlantic route. From this it is seen that payload, expressed as a percentage of the gross weight, increases as the weight increases and reaches a figure of 14 per cent. *W* at a gross weight of 100,000 lb., and at 200,000 lb. the payload amounts to as much as 16½ per cent. *W*. It is interesting to note how the payload percentage for flight-refuelled air liners

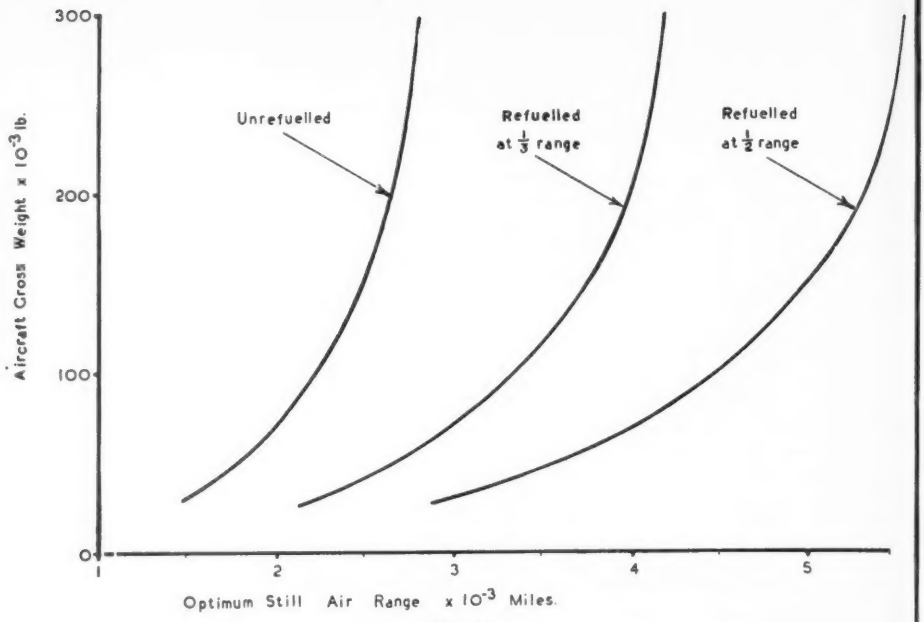

Fig. 10.
Aircraft size versus optimum range. Unrefuelled and flight-refuelled.

increases with gross weight in contradistinction to the diminishing percentage of unrefuelled aircraft designed for long distance routes.

It has already been shown how flight-refuelling renders unnecessary the construction of very big air liners for the North Atlantic and other long-distance routes. Fig. 12 shows that the flight-refuelled aircraft may be between one-half and one-third the size of one designed to take off with sufficient fuel for a 5,000 mile flight. The effect on capital and running costs is important: the initial cost of aircraft, the cost of insurance, the cost of fuel and oil, and the cost of maintenance are all roughly directly proportional to the size of aircraft, while the problems associated with the design and construction of out-size aeroplanes prolong the periods both of building and testing.

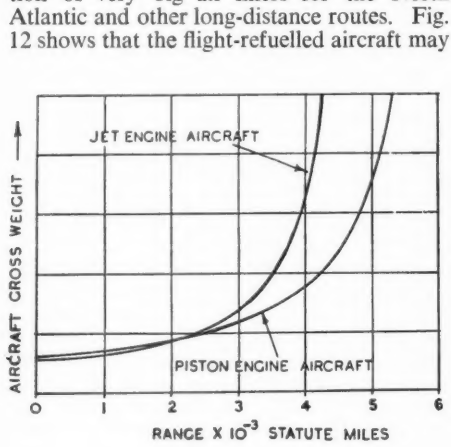

Fig. 11.
Effect of range on aircraft size—constant payload.

The question of operational ancillaries is of no less importance: the present rapid growth of aerodromes and hangars can be arrested and the rate of increase kept to a fraction of that obtaining today. The strength of runways is dictated entirely by the load to be supported and the heavy weight of some of the newer types of aircraft is presenting a problem of considerable magnitude.

The large aeroplane requires aerodromes of adequate size, not only at the termini and intermediate stopping places, but also at all emergency and alternative aerodromes.

The next two diagrams have been prepared, from information supplied by Masefield in his British Commonwealth and

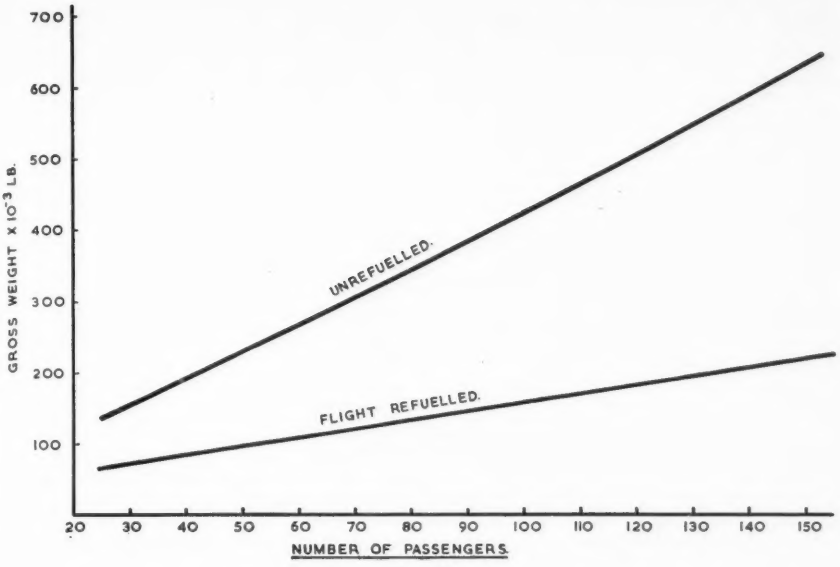

Fig. 12.
Required gross weight of aircraft for North Atlantic route. London-New York non-stop.

Empire Lecture, to illustrate how the cost of aircraft increases with growth of size and also, how profits for ton-miles tend to fall away with increase of the route stage length.

The increasing cost for units of weight of air liners with growth of gross weight, Fig. 14, is largely due to the smaller number of large aircraft produced and the higher development cost.

Masefield's figures are largely borne out by E. P. Warner, who, in the 1943 Wilbur Wright Memorial Lecture*, gave the cost of civil aircraft as varying as $W^{1.25}$. Thus, if the unrefuelled trans-Atlantic air liner is $2\frac{1}{2}$ times the weight of a flight-refuelled air liner, the cost will be 3.15 times as much.

The falling off of potential profits with stage length, Fig. 15, has been based on Figs. 41 and 42 of Masefield's Lecture. The full line curve has been drawn to pass through the peaks of profit curves for short, medium, and large aircraft of contemporary types, and therefore infers that the most economic size is employed for each stage length. Despite this, the diminishing ratio of payload/fuel load and the tendency for revenue rates to fall for longer journeys, cause a decrease in the capacity ton-mile profit-making capacity with increase of stage length, dropping to zero, probably, a little in excess of 4,000 still-air miles.

The profit trend with flight-refuelled services is added as a chain-dotted line: it

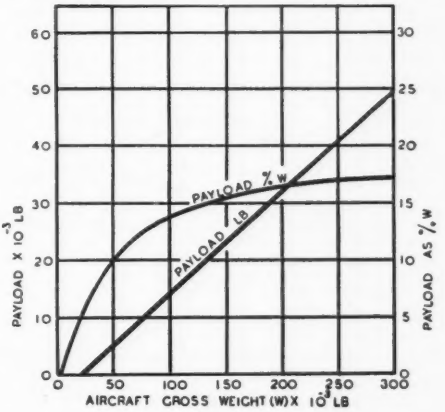

Fig. 13.
Payload of flight-refuelled passenger air liners—London-New York.
Reciprocating engines.

*31st Wilbur Wright Memorial Lecture: Post-War Transport Aircraft, E. P. Warner, Hon.F.R.Ae.S., JOURNAL R.Ae.S., July 1943.

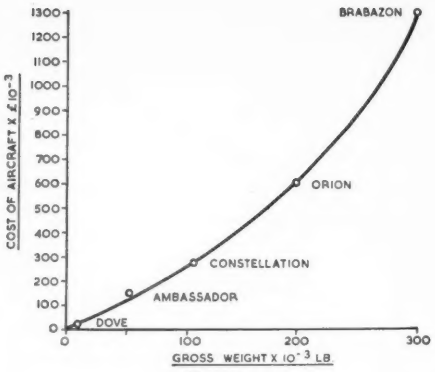

Fig. 14.
Aircraft cost.

crosses the first curve at a stage length of approximately 2,500 still-air miles.

These curves relate to air liners powered with reciprocating engines and the figure has been spotted with three points as calculated for the D.H. Comet on the London-New York route for annual utilisation of 3,100 hours and 5,000 hours, the greater profit-making capacity rate for the Comet being due to its high cruising speed.

2. CIVIL AIRLINE APPLICATION

2.1. D.H. COMET NON-STOP SERVICE, LONDON-NEW YORK

A practical example of a flight-refuelled service on a civil air route is supplied by the operation of the D.H.106 Comet between London and New York. The Comet at present has a payload capacity of 12,000 lb. (36 seats) at a gross weight of 105,000 lb., but in its developed state it is expected to have a payload of 14,000 lb., for a weight of 110,000 lb.

On the westward journey, the capacity payload (both versions) can be carried against a 91 m.p.h. head wind, giving a 90 per cent. winter regularity. Refuelling would take place up to approximately 250 miles beyond Shannon, at which point the fuel transfer would be 2,020 gallons, and over Gander, where 1,600 gallons would be transferred (Fig. 16).

In the event of a refuelling failure, the Comet would be able to return to London, if necessary, from the first refuelling point, and to fly on to Halifax from the Gander refuelling position. The fuel transferred at Gander would enable the Comet to reach Washington, as an alternative aerodrome for New York, but if desired considerably more fuel could be taken on to increase the reserve at New York.

Flying eastward, one refuelling only would normally take place, this being located in the vicinity of Gander, although in an emergency, the Shannon tanker could be called upon. Again, capacity payloads could be transported at a winter regularity of 90 per cent. (Fig. 17).

The journey times, with average winds, would be 9½ hours and 7½ hours respectively,

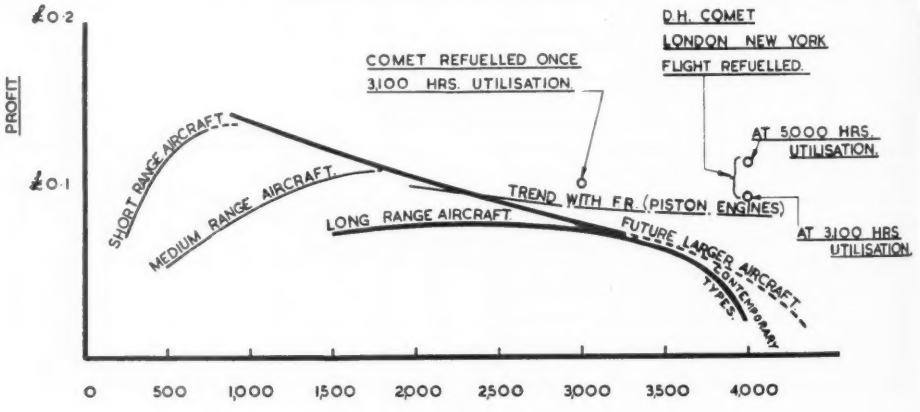

Fig. 15.
Profit a capacity ton/mile in still air.

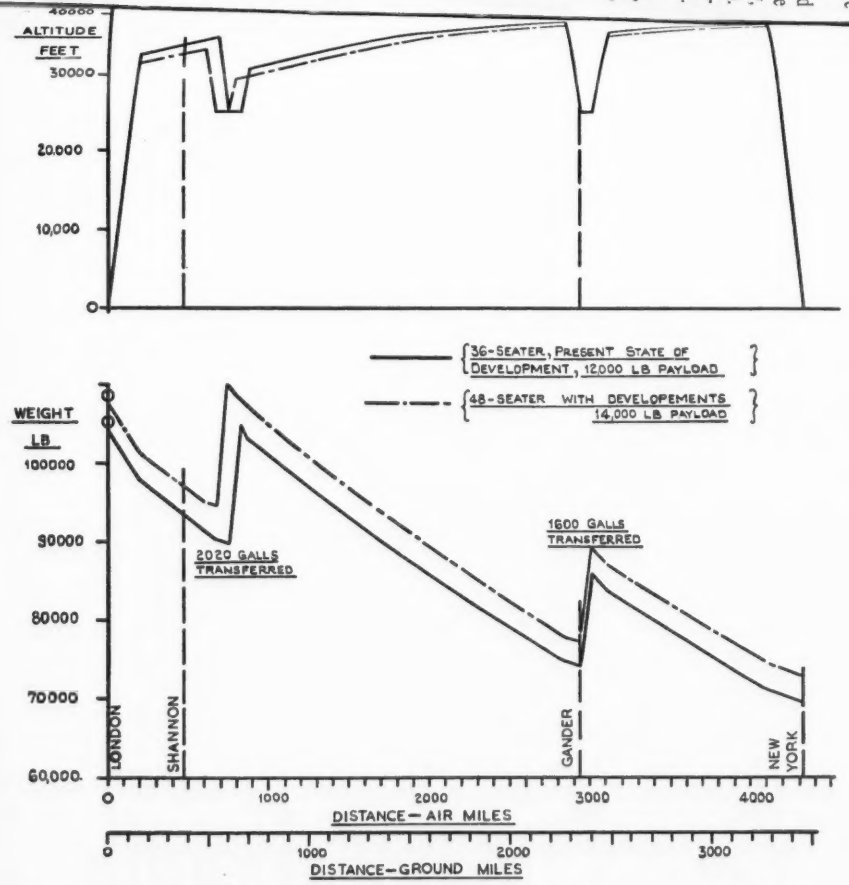

Fig. 16.

D.H. 106 Comet. North Atlantic operation with flight-refuelling.
Westbound journey with 91 m.p.h. head wind giving 90 per cent. winter regularity.
Atmospheric temperature—I.C.A.N.

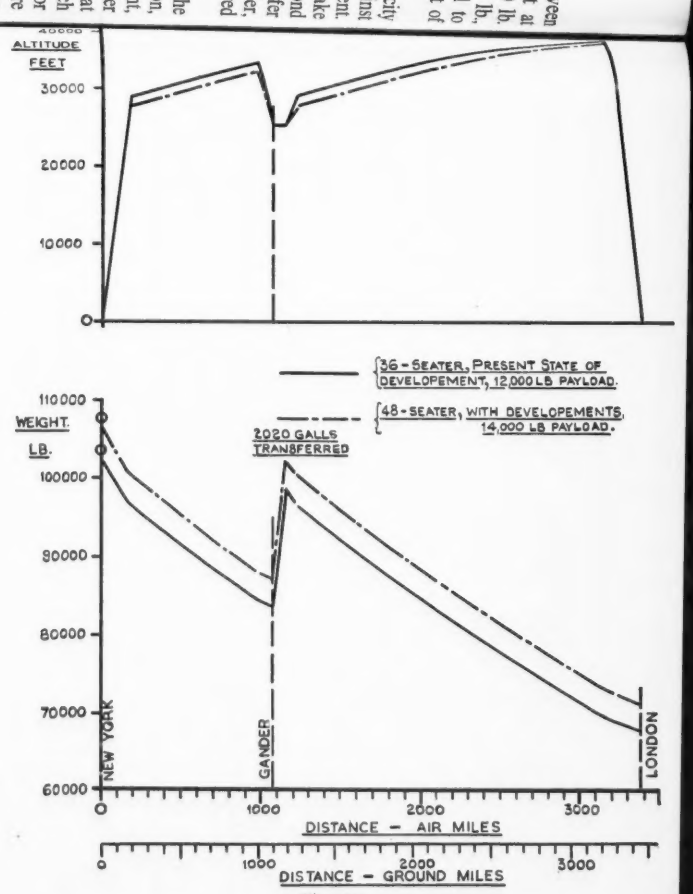

Fig. 17.

D.H. 106 Comet. North Atlantic operation with flight-refuelling.
Eastbound journey with 16 m.p.h. tail wind giving 90 per cent. summer regularity.
Atmospheric temperature—I.C.A.N + 10°C.

or roughly half the fastest present scheduled times. This would give a return trip in 17 hours, which means that for the first time a single aircraft would be capable of making the double crossing in 24 hours, allowing a turn-round time of 3½ hours at each terminus. The Comet could thus provide a daily return service on six days a week, leaving one day for maintenance. In this way, a utilisation of 5,000 hours per annum becomes a practical proposition.

2.2. Flight-refuelled compared with stopping service

Again using the D.H. Comet on the North Atlantic route as an example, and allowing for landings at Shannon and Gander, a 95 per cent. (annual) regularity is impracticable for the stopping service. Failing the use of Iceland as an additional stop under conditions of high wind, the stopping service allows only for a regularity of 85 per cent.; even so reduction in payload, with increases in journey time (and consequent reduction in utilisation factor) are suffered. Table I gives the main details of the two services.

The equalisation of payload in both directions is also a feature of the flight-refuelled service.

Table I

D.H. Comet on London-New York Route

	Flight Refuelled	*Stopping Service*
WESTBOUND		
Annual Regularity, %	95	85
Payload at 105,000 lb.	12,000 lb.	2,500 lb. (equipped for 28 passengers)
Payload at 110,000 lb.	14,000 lb.	8,350 lb. (equipped for 36 passengers)
Journey time, in average winds	9.5 hrs.	12.15 hrs. (including two stops of one hour each)
EASTBOUND		
Annual regularity, %	95	85
Payload at 105,000 lb.	12,000 lb.	11,000 lb. (only 28 passengers)
Payload at 110,000 lb.	14,000 lb.	12,000 lb. (only 36 passengers)
Journey time, in average winds	7.5 hrs.	8.85 hrs. (including one stop of one hour)

2.3. Profitability of the non-stop service

An estimate of Comet profit-making capacity on the North Atlantic route, with flight-refuelling from Shannon and Gander, has been made on the basis of revenue rates given by Masefield and airline costs calculated by the S.B.A.C. Standard Method*.

2.3.1. *Revenue and utilisation*

Schedules based on a return flight of 17 flying hours under working maximum conditions show that high utilisations are practicable, with ample provision for maintenance, as given in Table II and illustrated in Fig. 18.

Representative revenue figures given by Masefield have been used because, although somewhat out of date, they enable direct comparisons to be made between the Comet and the other aircraft treated in his paper. As fare rates have risen in the meantime, the current picture would be better than that shown here.

Then at a passenger load factor of 65 per cent.,

Total load	=	3.93 tons
Passenger revenue	=	£0.66 a mile
Freight revenue	=	£0.083 a mile
Mail revenue	=	£0.375 a mile
Total revenue	=	£1.118 a mile

Also,

Revenue a capacity ton mile = £0.204

Revenue a revenue ton mile = £0.285

Table II

Airline Operation

Return Services a day	*Fleet Strength*	*Total hours per annum*	*Utilisation*
1	2	6,200	3,100
2	3	12,400	4,133
3	4	18,600	4,650
4	5	24,800	4,960

It has been assumed that a total payload capacity of 12,000 lb. would be made up, at 100 per cent. load factor, approximately as follows:—

Mail	0.5 tons
Freight	0.5 tons
Passengers	4.5 tons

*Standard Method for the Estimation of Direct Operating Costs of Aircraft, S.B.A.C., September 1949.

Gross revenues at other passenger load factors are given in Table III.

2.3.2. *Costs*

Direct operating costs for the Comet have been calculated by the S.B.A.C. Standard Method, with assumptions where Comet technical and cost data are not yet available, as follows:—

ANNUAL COSTS

Comet cost, £450,000. Engines at £25,000 each.

Obsolescence (at utilisation of 3,100 hours)

	an hour
Equipped airframe and spares	£12.4
Power plant and spares:	£4.83
Insurance (at utilisation of 3,100 hours):	£8.9
Total Annual Costs at 3,100 hours utilisation:	£26.13

Similarly

Total Annual Costs at 4,133 hours utilisation:	£19.6
Total Annual Costs at 4,650 hours utilisation:	£17.4
Total Annual Costs at 4,960 hours utilisation:	£16.3

FIXED HOURLY COSTS

	an hour
Airframe and equipment maintenance and overhaul:	£30
Power Plant maintenance:	£3.32
Power Plant overhaul:	£25.8
Total	£59

"VARIABLE" HOURLY COSTS

	an hour
Air crew:	£10
Fuel:	£87
Landing Cost:	£2.35
Total	£100

Total indirect costs, which include the foregoing annual costs, may best be taken as 66 per cent. of the total hourly costs at 3,100 hours utilisation; the category of fixed hourly costs first being reduced to exclude workshop overheads, which are taken as 50 per cent. of basic labour.

So, Fixed Hourly cost (amended)	=£39 an hour
"Variable" Hourly cost	=£100 an hour
Indirect Cost=66 per cent. of £139	=£92 an hour
Total airline cost (excluding flight-refuelling)	=£231 an hour
Estimated cost of flight-refuelling*	=£64 an air liner hour
Total Cost	=£295 an hour
	=£0.109 a capacity ton/mile
At 65 per cent. passenger load factor	=£0.153 a revenue ton/mile

2.3.3. *Profits*

Revenue less cost, then, gives a profit, at a 65 per cent. passenger load factor, of:—

£0.095 a capacity ton/mile
and £0.132 a revenue ton/mile

Table IV gives the variations of cost with frequency and utilisation and of revenue with load factor. These relations are shown graphically in Fig. 19. It is evident that a Comet service could be run profitably on the North Atlantic even if the estimates of various cost items used here were very much less favourable. Overheads are likely to be greater than those assumed and utilisation may not be the maximum possible, but if the present cost estimate were doubled, the Comet would still break even at a 75 per

*This is dealt with in a later Section.

TABLE III

Passenger Load Factor	*Total Payload (Tons)*	*Gross Revenue*					
		Passenger per Mile	*Mail and Freight per Mile*	*Total per Mile*	*For Capacity Ton/Mile*	*For Revenue Ton/Mile*	*For Flying Hour*
85%	4.82	£0.863	£0.458	£1.321	£0.24	£0.275	£646
75%	4.37	0.76	0.458	1.218	0.222	0.279	598
65%	3.93	0.66	0.458	1.118	0.204	0.285	550
55%	3.48	0.56	0.458	1.018	0.185	0.293	500

Fig. 18.
D.H. Comet. Utilisation, fleet strength and total hours.

cent. load factor, and would be better at the present rate of passenger fares.

The fall of the cost curve with increasing frequency is not great as calculated, but allowance has not been made for economies of large scale which should take effect on "fixed" hourly costs of maintenance and overhaul and on indirect costs as the scale of operations increases. The effect of such economies would make the cost curve continue to fall as fleet size, on all routes, increased to 10, 20, or 30 or more Comets.

The final economic test of the flight-refuelled Comet service is its comparison with the best unaided stopping service on the same route. The Comet profit of £0.132 per revenue ton/mile at 3,100 hours utilisation and 65 per cent. passenger load factor, may be compared with the maximum long-range profit of £0.08 given by Masefield for the Constellation at a stage length of some 2,400 miles.

2.4. The Cost of Flight-Refuelling

When the planning of the refuelling operation for an air liner for maximum payload and regularity is completed, the cost of the refuelling service may be calculated from the known position and altitude at which refuelling takes place, the consequent performance required of the tanker and the schedule of airline flights a day.

Table IV

D.H. 106 Comet. Variation of Cost With Frequency and Revenue With Load Factor

No. of Return Services a day	*Air liner Fleet Strength*	*Air liner Annual Utilisation*	*COSTS AN HOUR*					*GROSS REVENUE AN HOUR*			
			Airline Costs			*Cost of Flight-Refuelling*	*Total Cost*	*85% Passenger load factor*	*75% Passenger load factor*	*65% Passenger load factor*	*55% Passenger load factor*
			Direct	*Indirect*	*Total*						
1	2	3,100	£139	£92	£231	£64	£295				
2	3	4,133	139	69	208	49	257	£646	£598	£550	£500
3	4	4,650	139	61	200	44	244				
4	5	4,960	139	57	196	42	238				

The tanker station has no exact counterpart in the civil or military sphere, its operational requirement being for a number of relatively short flights a day to be flown with great precision of timing and navigation. Its possible geographical remoteness demands self-sufficiency from the maintenance aspect, for the serviceability of its tankers is an absolute requirement to ensure that regularity of service is 100 per cent. Although aircraft utilisation may be low by civil standards and regularity requires some duplication of facilities, the cost of operation does not have to bear the commercial expenses and other overheads of an airline and the station may be stripped to necessities.

A standard "task and cost chart" has been developed to facilitate costing and has been used to estimate the cost of a flight-refuelling service for non-stop North Atlantic schedules by the D.H. 106 Comet and the Bristol 175. This shows that with three refuellings a day from one station, made at an altitude of 20,000 feet, at a radius of some 200 miles, the total cost for refuelling is of the order of £250. It has been calculated by Masefield that the average air liner landing and take-off cost for ton of gross weight amounts to £4 19s. 0d., so that a flight-refuelling cost of £250 may be equal to the sum saved by the avoidance of a landing by an aircraft of about 135,000 lb. In this case all the other flight-refuelling benefits of increased payload, shorter and non-stop flight, and so on, are gratis.

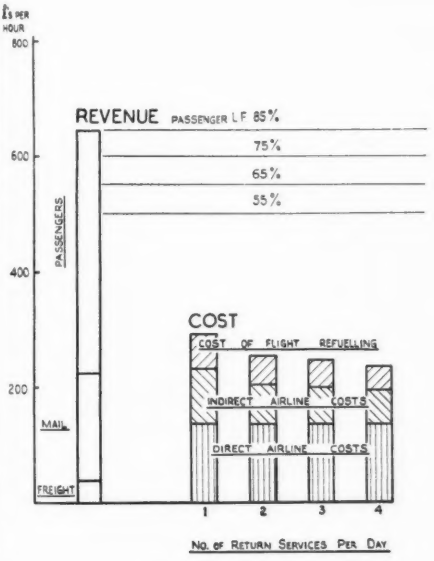

Fig. 19.
D.H. Comet cost and revenue an hour, London-New York non-stop, flight-refuelled.

Figures 20 and 21 show the trend of flight-refuelling costs for flying hours and for operation against distance from base to refuelling point for up to four refuellings a day. Unit cost tends to become constant at this frequency as a result of the accepted concentration of airline schedules; but it would continue to fall if higher frequencies could be spread evenly over the 24 hours.

Figure 21 shows also that the cost of a refuelling operation remains sensibly constant as distance to the refuelling point increases, up to a certain point. This is because a certain period of time is necessary for climbing to the required operational height and this may be made use of for travelling in any desired direction for contacting the receiver aircraft: thus for each height there is a circle centred on the tanker's base within which the flying time varies but little. This means that an "over-base" refuelling permits of considerable elasticity in all directions.

The cone of constant cost has a diameter of 200 miles at 10,000 ft. extending to about 560 miles at 25,000 ft. altitude.

3. MILITARY APPLICATION

The problem of refuelling aircraft engaged on civil airline operation is comparatively simple, since the stage length is a known quantity and remains constant, whereas the operation of military aircraft is considerably more complex. In the first place there are the different types of aircraft, *e.g.* bomber, fighter, and secondly, the several roles in which each type can be employed, their functions in some cases overlapping; and thirdly there is the ever-changing pattern of war with changing target distances and spheres of enemy occupation. Such factors render difficult precise analysis of all possible combinations of circumstances and methods of operation.

The bomber, more than any other type, lends itself to a reasonably comprehensive analysis, and a series of formulae has been developed to show how range and bomb load can be increased by one, two, or more

Fig. 20.
Cost of flight-refuelling.

refuellings, positions of optimum refuelling points, maximum bomb load, and so on.

In many instances the formulae thus derived can be applied to other functional requirements: for example, the extreme case of the bomber with zero bomb-load is directly applicable to the photographic reconnaissance aircraft. The flight-refuelled fighter is not so amenable to mathematical treatment and because of this it will be dealt with first in more general terms.

3.1. Fighter aircraft

The provision of adequate range for fighter aircraft has presented a problem of no small magnitude for many years and the position has become more acute with the introduction of jet-engined fighters, on account of their relatively low endurance, with consequent restriction on the period available within an offensive area.

Perhaps the simplest conception of the refuelling in flight of fighters is the transfer of fuelling operations from the ground to the air by the simple expedient of stationing tankers above the home base. Fighters returning from sorties, for refuelling prior to re-engagement, can make direct contact with the tankers, and having replenished their tanks in the matter of two or three minutes can depart immediately for a second or third sortie. The saving of time is assessed by comparing two or three minutes with the time required to descend from, say 25,000 feet, land, taxi to and from the fuelling point, refuel, take off and re-climb to altitude. The flight-refuelled fighter, with its full tanks, gains in endurance by an amount equal to that required for taxi-ing, take-off and climb, but perhaps the greatest advantage accrues from the fact that the fighter can return to an engagement after an absence of but a few minutes. In other words, the time saved is at a most vital period and thus permits the airborne force to be kept to a maximum. A corollary to this is the avoidance of sitting targets presented by grounded aircraft.

Developing this use of aerial refuelling, the tankers may be pushed forward towards the theatre of operations, thus adding still further to the increment of endurance.

Congestion at fighter bases can be appreciably reduced by the employment of this technique.

At the present time it is not possible to provide fighter escort for bomber formations engaged on long-range missions. It is possible, however, to include a number of aerial tankers in the bomber formation and for the accompanying fighters to replenish their tanks from time to time from these tankers. Although not essential, it would probably be best for the tankers to be of similar type aircraft to the bombers and they could be fully armed.

Tankers and fighters would be no more vulnerable during the refuelling operation than the bombers themselves because they would be covered by the remainder of the formation, while at the same time all possible steps would be taken to expedite the refuelling operation so that the fighters need not remain in contact for longer than one or two minutes. Obviously it would be arranged for the fighters to refuel in rotation, so that at all times the greater part of the fighter force would be available for defensive purposes.

When a fighter returns from an offensive sortie its base aerodrome may be unusable for weather or other reasons, and the fighter may have insufficient fuel to reach a suitable emergency landing field. If the fighter is equipped for flight-refuelling, it becomes possible for it to be met by a tanker and supplied with sufficient fuel to proceed to a safe landing.

Fighter aircraft can be given almost unlimited range by means of flight-refuelling, which means that ferrying operations to points at considerable distances can be made at relatively short notice and minimum expense, making unnecessary the present costly method of crating, shipping and rebuilding at the operational base. In many instances suitable dock facilities and airfield equipment are not available, so that without flight-refulling the despatch of fighters to such points presents a still greater problem.

3.2. Bombers

The problem of "bomb-load × range" has become particularly acute of late. Up to a point it was found that increase of both bomb load and range was possible by building larger and larger aircraft, but the point was reached beyond which this method gave steadily diminishing returns, and it is now seen that with known power units there is more or less a limit to the range an aircraft can fly, while any increase in the bomb load carried means a corresponding loss of range. Jet propulsion has provided greatly increased speed of flight, but has approximately doubled the fuel consumption measured in gallons a mile, so that the "bomb load × range" problem has become still further accentuated.

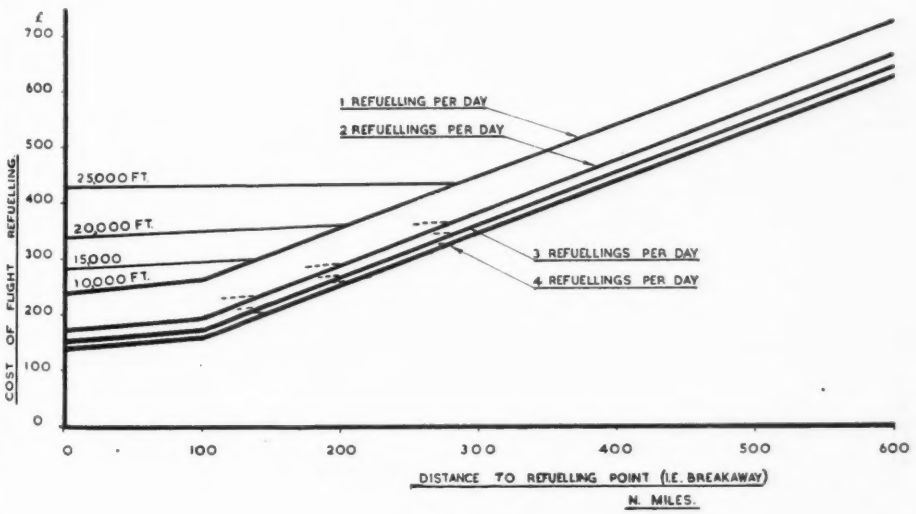

Fig. 21.
Cost of flight-refuelling.

The advantages of flight-refuelling can be measured in more than one way. In the first place if flight-refuelling enables a bomb load to be carried some distance greater than the normal range of the bomber aircraft, this in itself can be sufficient reason, irrespective of the effort involved. Secondly, if two aircraft are to be employed upon a bombing mission, and if it can be so arranged that one carries the full bomb load with the second acting as a tanker, the number of aircraft brought within the danger (target) area is halved. There is a third method of measuring the economy and that concerns the number of aircraft miles flown for unit weight of bombs dropped.

Although the economics governing civil and military aviation are not the same, there is some relationship.

As shown already, in order to obtain the maximum "payload × range" for a flight, the flight distance should be half the ultimate range that would be obtainable if all disposable load were in the form of fuel; this means that approximately half of the disposable weight would be in the form of fuel and the other half in the form of payload. For bomber aircraft bomb load is substituted for payload, and the fuel load is divided between the fuel required for the outward journey and fuel for the return, and the diagram is given on a radius base instead of range (Fig. 22).

Figure 23 shows first (the full line curves), the variation of bomb load with radius of operation, together with the curve giving "bomb load × radius," having its maximum at half the radius of operation. The efficiency of civil aircraft can be measured in terms of "payload × range," since revenue is directly proportional to this factor, but in military operations the factor of distance cannot be so easily taken into account. Generally

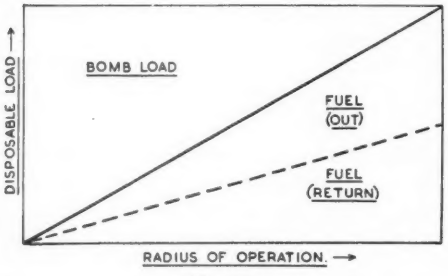

Fig. 22.

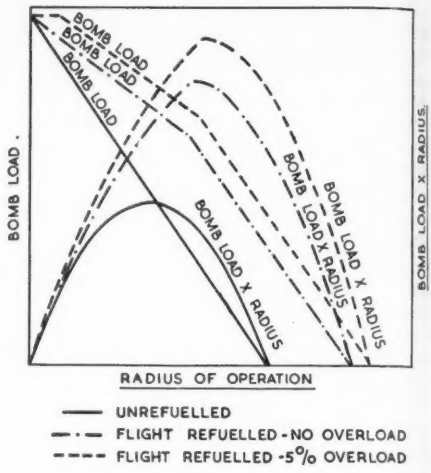

Fig. 23.
Bomb load and bomb load × range.
Unrefuelled and flight-refuelled bombers.

speaking, long range for a bomber is highly desirable, but the actual radius of operation is bound to be a variable within certain limits,depending upon the theatre of war and the distance of targets from base. In practice, the distance to the target is likely to vary from day to day instead of remaining constant, such as any given stage length along a civil air route. Thus the distance factor cannot be measured in the same manner, nevertheless the greatest efficiency in the operation of bomber aircraft is likely to accrue when the mean distance to the target is somewhere in the neighbourhood of half the ultimate range.

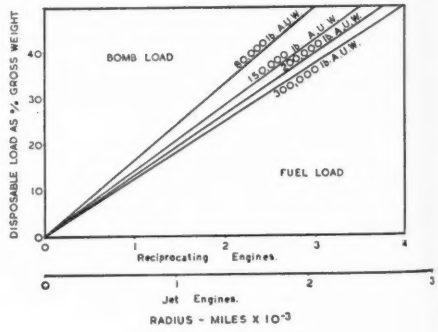

Fig. 24.
Division of bomber's disposable load.

Figure 23 also gives the variation of bomb load with radius of operation, together with the curve of "bomb load × radius" for a given bomber flight-refuelled. Two flight-refuelled cases have been considered, one with no over-load and the other with a 5 per cent. over-load after refuelling. In both flight-refuelled cases, refuelling takes place at the optimum point.

Comparing the unrefuelled with the flight-refuelled, plus a 5 per cent. over-load, flight-refuelling increases the maximum "bomb load × radius" by 100 per cent., and the radius at which this maximum occurs is increased by nearly 50 per cent.

In Fig. 7 it was shown that the ultimate range of a large military aircraft carrying no war load is in the neighbourhood of 8,000 miles for reciprocating engines and 5,750 miles for jet-propelled aircraft, and moreover that these figures are likely to be improved upon but slightly by further increase in gross weight. Below a weight of 300,000 lb. the ultimate range suffers reduction and is approximately 6,000 miles (4,200 miles for jets) at a gross weight of

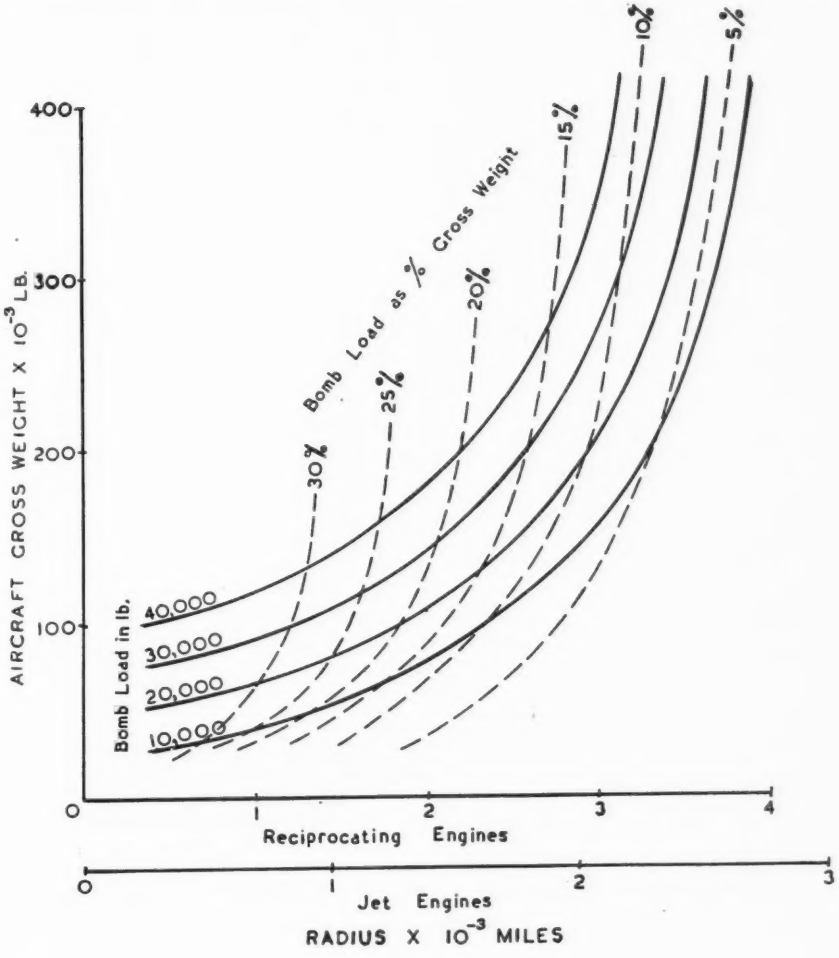

Fig. 25.
Bomber gross weight versus radius.

100,000 lb. Ranges greater than 8,000 miles have been achieved, but in general they have been obtained by the aid of assisted take-off and by the acceptance of some reduction in strength factors, due to overloading, during the early part of the flight.

Figure 24 is based on previous work and shows the division of disposable load between bomb load and fuel for bombers of various gross weights. If it can be assumed that maximum bomb ton/miles are obtainable when the operational radius is approximately half the ultimate, *i.e.* 2,000 still-air miles (1,400 miles for jets) for aircraft of not less than 200,000 lb. gross weight, the bomb load constitutes half of the disposable load, or approximately 25 per cent. of the gross weight.

For military operations a useful radius greater than 2,000 still-air miles (1,400 miles for jet bombers) is likely to be required and this can be obtained by a reduction of bomb load, although only at the expense of some loss of maximum effort as measured in war-load ton/miles. It is obvious from Fig. 24 that as the range approaches the ultimate, the corresponding bomb load becomes a small percentage of the aircraft gross weight and there must be a stage beyond which such operation ceases to be economic: for example, the bomb load of a 300,000 lb. piston-engined aircraft for a radius of 3,500 still-air miles is about 1/8th of the disposable load, or 1/16th of the gross weight. Thus an aircraft of 300,000 lb. would be expected to carry a bomb load no greater than 18,750 lb. over the distance quoted.

If a certain fixed bomb load is to be carried, Fig. 24 enables the size to be determined of the aircraft required to carry that bomb load to a target situated any distance up to the maximum. For example, if the bomb load is fixed at 30,000 lb., the aircraft gross weight required for a radius of 2,000 still-air miles would be approximately 140,000 lb. (235,000 lb. for jet aircraft), but

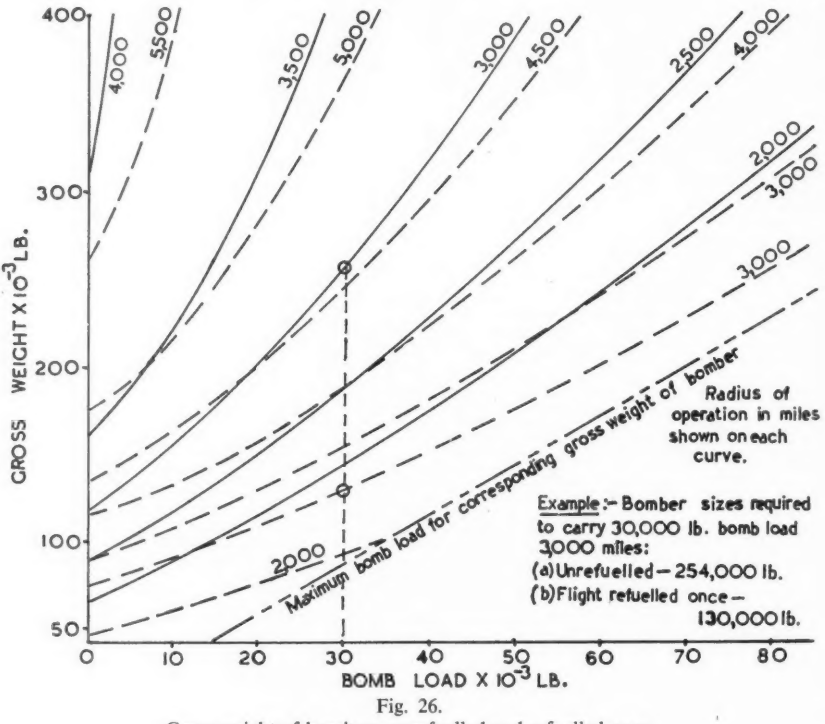

Fig. 26.

Gross weight of bombers, unrefuelled and refuelled once.

———— Unrefuelled. — — — Refuelled once.

if the radius is increased to 3,500 miles, the gross weight would increase to over 400,000 lb. for a bomber powered with reciprocating engines and would be impossible for a jet-powered aircraft.

Figure 25 shows the aircraft gross weight required to carry a given bomb load over any radius of operation, for bomb loads between 10,000 lb. and 40,000 lb. in steps of 10,000 lb. On the same diagram the bomb load has been plotted as a percentage of the gross weight. The diagram clearly shows that aircraft size increases rapidly at the higher end of the radius scale and becomes out of all proportion to the weight of bombs carried.

The effect of flight-refuelling on increasing the range of bombers is given later, but in order to demonstrate how the rapid growth with range in aircraft size can be arrested, Figs. 26 and 27 have been introduced at this stage. Fig. 26 gives a series of curves for various ranges, showing gross weight of bomber against bomb load carried, both under normal (unrefuelled) operation and with one refuelling in flight: thus, for example, a load of 30,000 lb. requires an aircraft (unrefuelled) of 254,000 lb. gross weight for a range of 6,000 miles, as against a weight of 130,000 lb. when refuelled once on the way to (or return from) the target. Similarly, Fig. 27 gives a series of curves showing the aircraft size required for various bomb loads over a series of ranges with the aid of two refuellings, *i.e.* one outward-bound, and one on the return, and for comparison the basic unrefuelled curves are again added. This diagram shows the great distances over which bomber aircraft can be operated with flight-refuelling, which are unachievable by any size of aircraft without resort to flight-refuelling.

To illustrate clearly the comparable sizes of bombers with and without flight-refuelling, Table V sets out for various bomb loads the sizes of aircraft unrefuelled and flight-

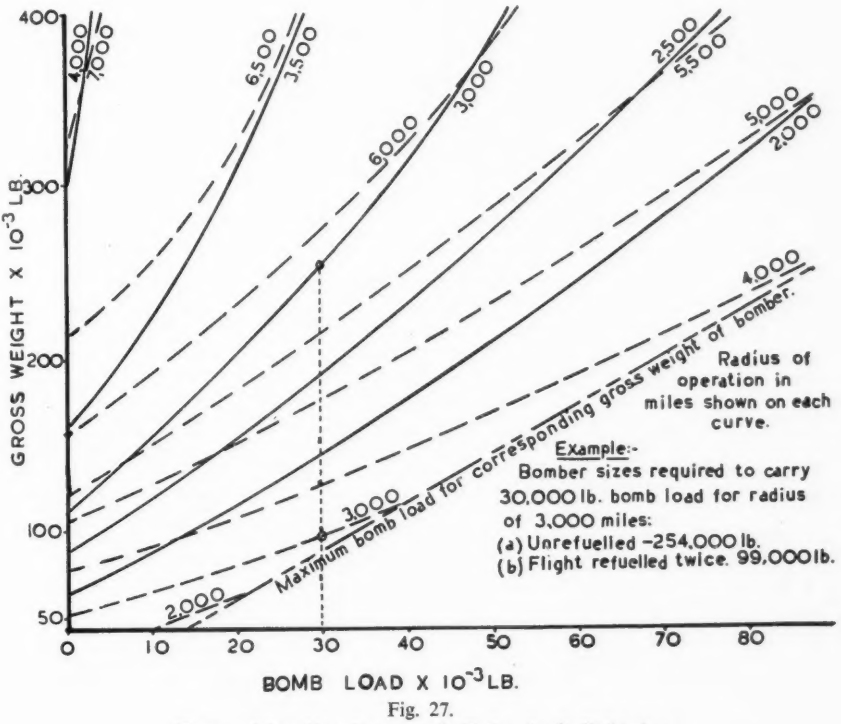

Fig. 27.

Gross weight of bombers, unrefuelled and refuelled twice.

——— Unrefuelled. — — — Refuelled once outwards and once returning.

refuelled as obtained from Figs. 26 and 27. All assume a required still-air range of 6,000 miles.

3.3. Optimum refuelling point

In order that the effect of the bomber/tanker combination shall be a maximum, the refuelling should be done at the optimum position. Formulae for calculating the position of the optimum refuelling point, radius of operation, and fuel transferred, have been evolved for the following conditions:—

(*i*) One refuelling out. No over-load.

(*ii*) One refuelling out. With over-load.

(*iii*) One refuelling out, one refuelling back. No over-load.

(*iv*) One refuelling out (with over-load), one refuelling back.

(*v*) Two refuellings out, one refuelling back. No over-load.

(*vi*) Two refuellings out (with over-load), one refuelling back.

(*vii*) Two refuellings out, two refuellings back. No over-load.

(*viii*) Two refuellings out (with over-load), two refuellings back.

In all the calculations it has been assumed that both the bomber and tanker are of the same basic design.

Only one case is given but the solutions for the remaining cases are calculated along similar lines*.

(*i*) One refuelling out. No over-load. (*See* Fig. 28.)

Table V

Comparable Weight of Aircraft, Unrefuelled and Flight-refuelled, for various Bomb Loads

Bomb Load lb.	*Gross Weight (lb.)*		
	Unrefuelled	*Flight-Refuelled*	
		One Refuelling	*Two Refuellings*
10,000	155,000	80,000	65,000
20,000	203,000	110,000	81,000
30,000	254,000	130,000	99,000
40,000	313,000	153,000	118,000

*The solutions for all cases are given in Flight Refuelling Report No. FR/CE/139.

Let b = maximum normal radius of operation of unrefuelled aircraft (assuming whole disposable load consists of fuel). Then the absolute range, unrefuelled, is $2b$.

$3a$ = total weight of fuel + bombs.

B = bomb load.

$\zeta = B/3a$

With no bomb load.

Fuel transferred

at any point = fuel consumed by tanker

= fuel consumed by bomber (for same distances flown).

= ½ fuel required by tanker to fly out to refuelling point and back.

Therefore maximum transferable = ⅓ total fuel.

Therefore

$$\text{refuelled range} = 2b + \frac{2}{3}b = \frac{8}{3}b$$

and refuelling radius (*i.e.* distance to target) $= \frac{4}{3}b$

Therefore

$$\text{refuelling point} = \frac{2}{3}b \quad . \quad . \quad (1)$$

i.e. Refuelling point is half way to target.

With bomb load.

$$\text{unrefuelled range} = (1-\zeta)2b$$

$$\text{and refuelled range} = \frac{2}{3}b + (1-\zeta)2b$$

$$= \frac{2}{3}b + 2b - 2b\zeta$$

$$= \frac{8}{3}b - 2b\zeta$$

Therefore

$$\text{refuelled radius} = \frac{4}{3}b - b\zeta$$

$$= b\left(\frac{4}{3} - \zeta\right) \quad . \quad (2)$$

Refuelling point $= \frac{2}{3}b$ as before.

Fuel transferred $= a$ . . . (3)

As the bomb load increases, the radius of action and optimum refuelling point converge. They coincide when the radius of action is at $\frac{2}{3}b$.

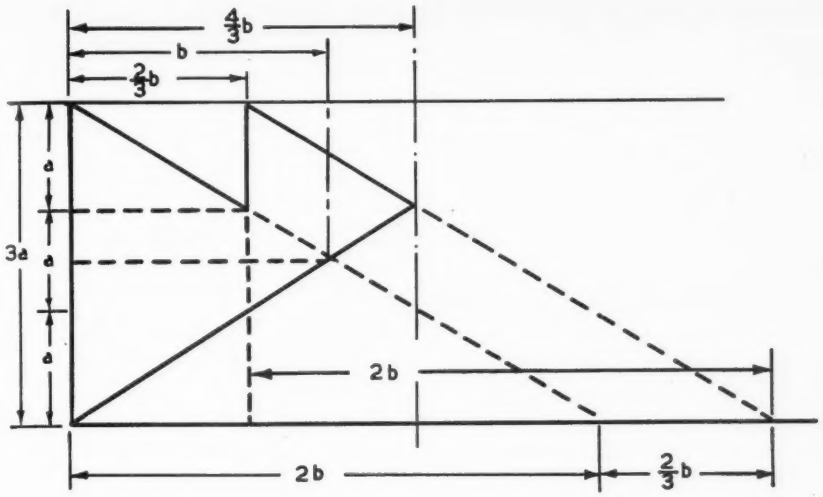

Fig. 28.
Case (1). 1 refuelling out, no over-load.

But refuelled radius $= b\left(\frac{4}{3} - \zeta\right)$

Therefore $\frac{2}{3}b = \frac{4}{3}b - b\zeta$

$$b\zeta = \frac{2}{3}b$$

$$\zeta = \frac{2}{3}$$

Therefore

bomb load $= 2a$ . . . (4)

Figure 29 shows the effect of flight-refuelling on the bomber's range/bomb load capabilities, the bomber being roughly equivalent to the B-50. If the radius of operation is less than the distance to the optimum refuelling point, flight-refuelling is not efficacious, since a larger weight of bombs can be dropped by using the tanker as a bomber. This is due to the fact that when the tanker is not required to go to the optimum point, it would either have a quantity of fuel remaining in the tanks on landing, or take-off at less than its full operational weight, and therefore full use would not be made of the bomber-tanker combination. There is a case, however, for using flight-refuelling for the shorter ranges and that is when the bomb load carried is made up of one very large bomb, *i.e.* a bomb load that cannot be shared by two bombers. The effect of flight-refuelling, with over-load, on the bomber's performance is also shown on Fig. 29.

Re-fuelling operations at or near a target would not be desirable; also, the extreme radius of a refuelled bomber (with zero

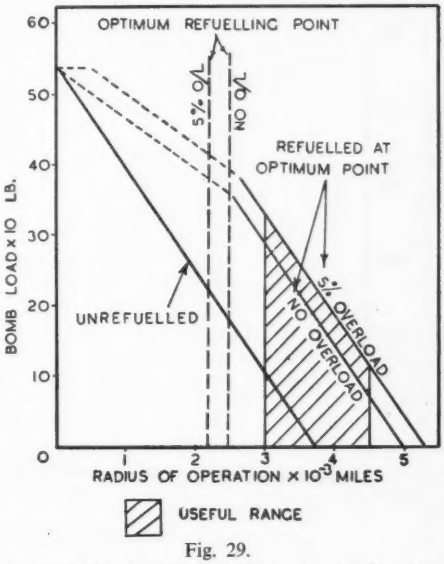

Fig. 29.
Hypothetical bomber (B-50 type) operational capabilities.

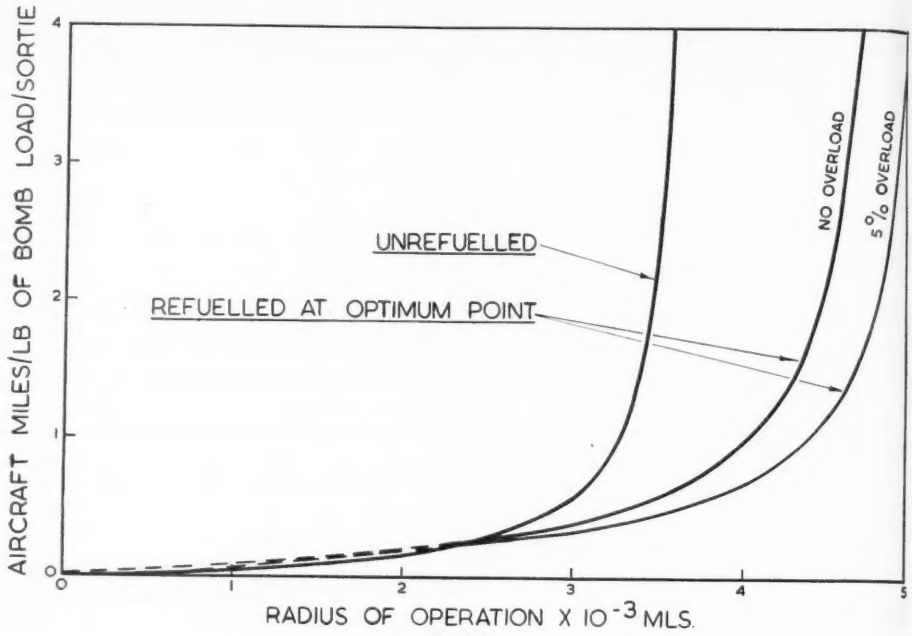

Fig. 30.
Aircraft miles for unit bomb load. Refuelled and unrefuelled (B-50 type).

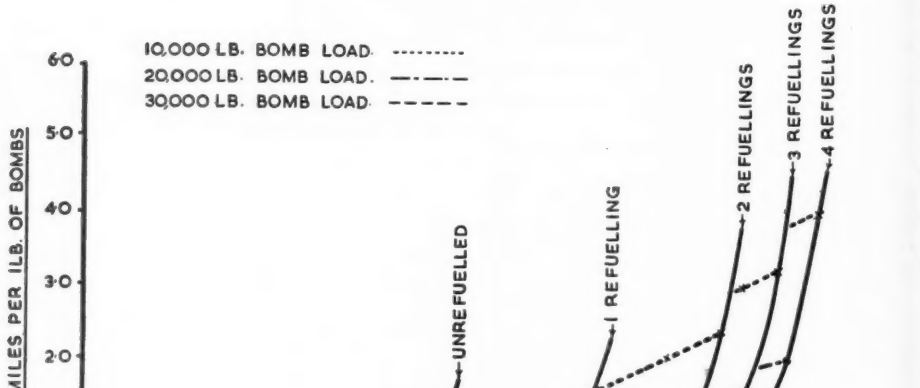

Fig. 31.
Total air miles for one lb. of bombs dropped for conventional type bomber (B-36).

bomb load) would not be a practical operation and on Fig. 29 a suggested useful range of a flight-refuelled bomber is indicated by the shaded portion.

As the bomb load is increased, so the refuelling point and the radius of operation tend to coincide. They meet, in the case considered, for the no-over-load condition, at a radius of about 2,500 miles with a bomb load of 36,000 lb., and remain coincident to zero range. This is shown by lines dotted on the figure and over this part the tanker is operating below its maximum effort. Assuming that it is required to drop the maximum possible bomb load where normally the target and refuelling point coincide, and that a double refuelling would be impossible, or at least undesirable, over-loading would have to be resorted to in order to refuel away from the target area. In the double refuelling case, the tanker would transfer part of its fuel load to the bomber some distance short of the target, and would then orbit that point until the bomber returned, when it would deliver the remainder of the fuel. In this case the maximum bomb load could be dropped without any over-loading.

In order to show the economy of operation of a flight-refuelled bomber over an unrefuelled bomber, Fig 30 shows the combined aircraft miles flown for unit weight of bombs dropped, over the complete range of operational radii considered. For the longer ranges the economy is considerable. The dotted portion for the shorter ranges indicates that slightly greater air miles are flown for unit weight of bombs for the flight-refuelled cases. This is based on the assumption of one tanker for one bomber. As the tanker under these conditions works at below its maximum capabilities, it would be possible for it to supply more than one bomber and so bring about an improvement in the air miles flown for unit weight of bombs.

Figure 31 shows the air miles flown for unit weight of bombs for various numbers of refuellings for the B-36 type of bomber and covers the following cases, with an overload after refuelling of 20,000 lb., or 7.2 per cent.: —

Unrefuelled.
One refuelling out.
One refuelling out, one refuelling back.
Two refuellings out, one refuelling back.
Two refuellings out, two refuellings back.

The increase in radius of operation for one and two refuellings is considerable, while a third and fourth refuelling bring about somewhat smaller increases.

The unrefuelled range for zero bomb load is a hypothetical range based on the assumption that sufficient capacity would be available for the fuel.

The effect of flight-refuelling on the range and bomb load performance of individual bombers has been dealt with at some length and it is of interest to apply the results to a bomber force and to note the effects.

Figures 32 and 33 summarise the effects on a force of 100 aircraft of the B-50 type and a comparison is made of an unrefuelled force and a flight-refuelled force with both one refuelling and two refuellings. The figure of 100 bombers has been selected as a convenient unit which may be scaled up or down as required. In the unrefuelled case the whole force of 100 aircraft is assumed to be bombers and in the refuelled cases the force is made up of bombers and tankers, one half bombers and one half tankers for one refuelling, and one third bombers and two thirds tankers for two refuellings.

Figure 32 deals with one refuelling, with and without over-load, normally carried out on the outward journey, but similar results are obtainable when carried out on the homeward journey, except that the over-load state is not possible.

Diagram (*a*) gives the total bomb load dropped for the whole force.
(*b*) gives the miles flown for ton of bombs dropped.
(*c*) gives the number of aircraft over the target for 100 tons of bombs, and
(*d*) shows the bombing concentration in tons a minute.

Figure 33 deals with the same four factors for two refuellings, one outward and one returning.

Flight-refuelling is essentially a long-range weapon, and it is observed that there is a region (below approximately 2,600 still-air miles radius, in the case considered) in which flight-refuelling is not economic, besides which the refuelling point and target coincide within this region. As the operational radius is extended beyond the critical point, the effects of flight-refuelling are to increase the weight of bombs dropped, to decrease the aircraft miles flown for unit weight of bombs, to reduce the number of aircraft over the target area, and to increase the concentration of bombing.

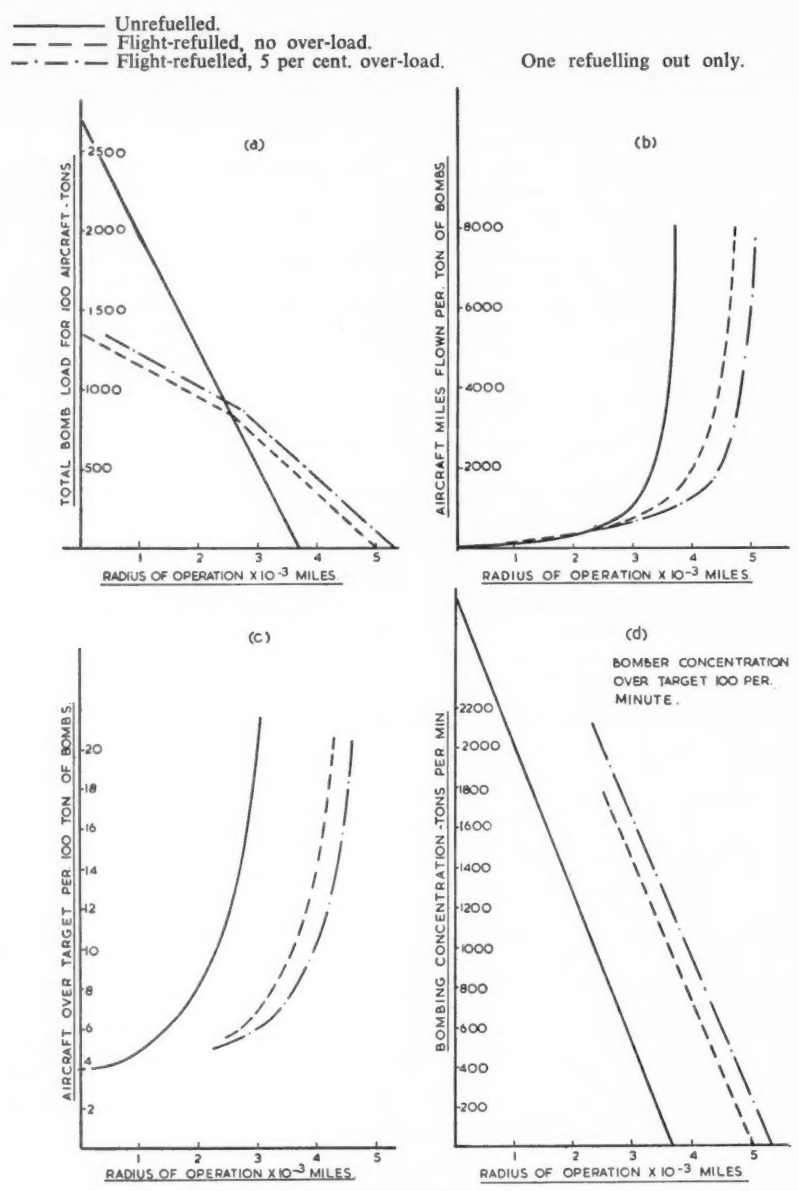

Fig. 32.
The effects of flight-refuelling a bomber force (B-50 type aircraft).
Strength of force—100 aircraft.

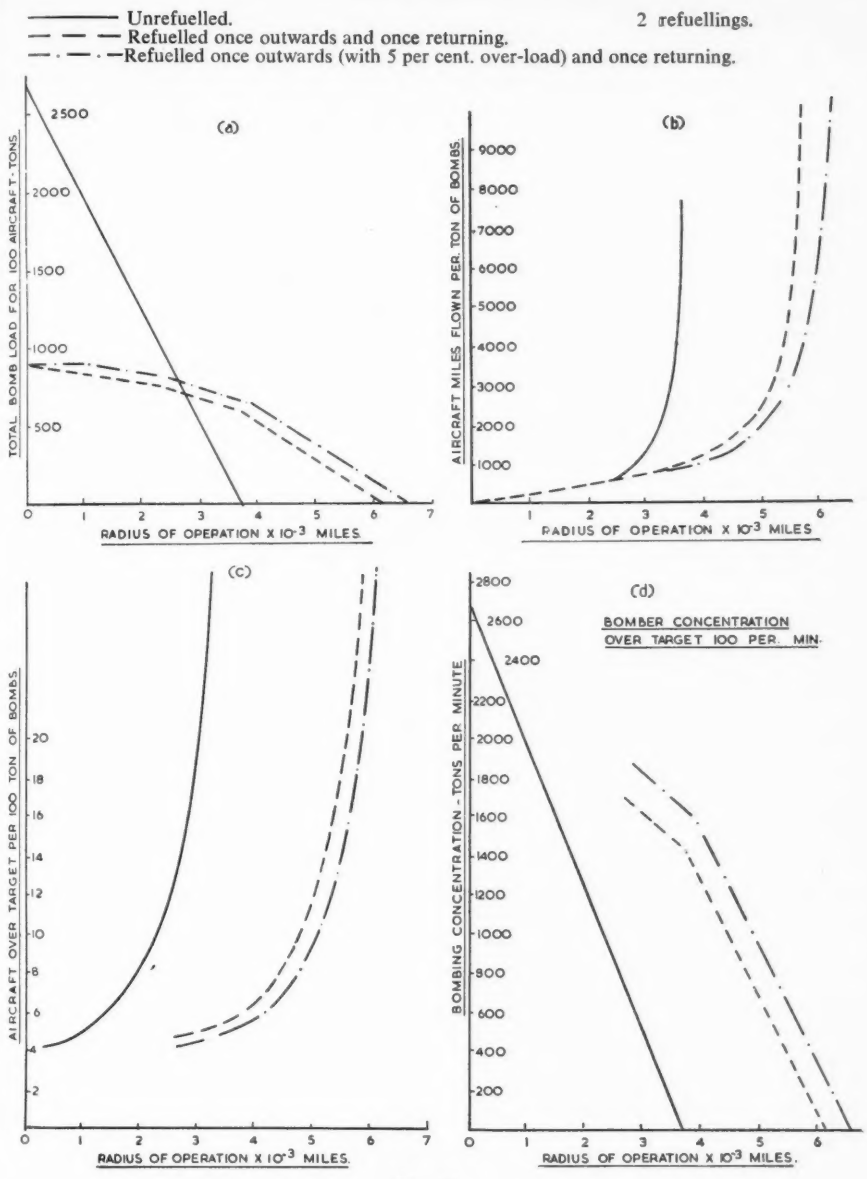
Unrefuelled.
Refuelled once outwards and once returning.
Refuelled once outwards (with 5 per cent. over-load) and once returning.
2 refuellings.
(a)
TOTAL BOMB LOAD FOR 100 AIRCRAFT - TONS
RADIUS OF OPERATION X 10-3 MILES
(b)
AIRCRAFT MILES FLOWN PER TON OF BOMBS
RADIUS OF OPERATION X 10-3 MILES
(c)
AIRCRAFT OVER TARGET PER 100 TON OF BOMBS
RADIUS OF OPERATION X 10-3 MILES
(d)
BOMBER CONCENTRATION OVER TARGET 100 PER MIN.
BOMBING CONCENTRATION - TONS PER MINUTE
RADIUS OF OPERATION X 10-3 MILES

Fig. 33.
The effects of flight-refuelling a bomber force (B-50 type aircraft).
Strength of force—100 aircraft.

APPENDIX

An analysis of the profit-earning capacity of aircraft, with and without flight-refuelling

The effectiveness of flight-refuelling on the operation of load-carrying aircraft can best be illustrated by an analysis of the revenue-earning capacity of an aeroplane with and without the aid of flight-refuelling.

The amount of useful load that can be carried depends upon the weight of fuel and is thus almost inversely proportional to the range flown. If fuel consumption, throughout the flight range, is assumed to be constant* the "payload versus range" curve is a straight line, as shown in Fig. A1.

Let payload be "p" tons for any range "r" miles, and let maximum payload (zero range) be P, and maximum range (without refuelling) (zero payload) be R.

Then payload for any range is:—

$$p = \frac{P}{R}(R - r) = P\left(1 - \frac{r}{R}\right)$$

Multiplying "p" by "r" gives the curve of Revenue ton miles versus range, which is a parabola as indicated in Fig. A1. The maximum ordinate is obviously at half the ultimate range, where $p = \frac{P}{2}$ and $r = \frac{R}{2}$

*The results are but little affected if the true fuel consumption be used.

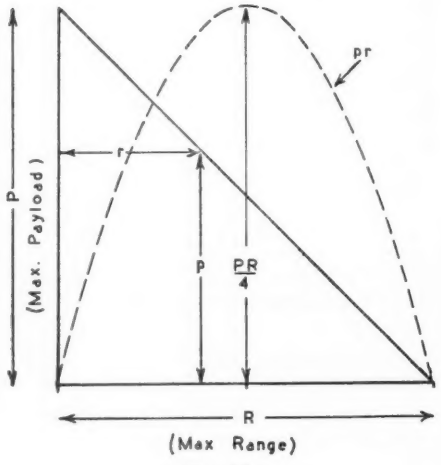

Fig. A1.

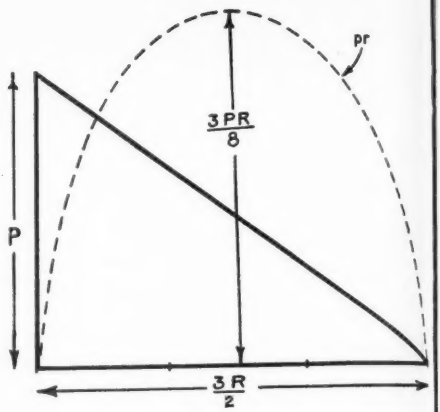

Fig. A2.

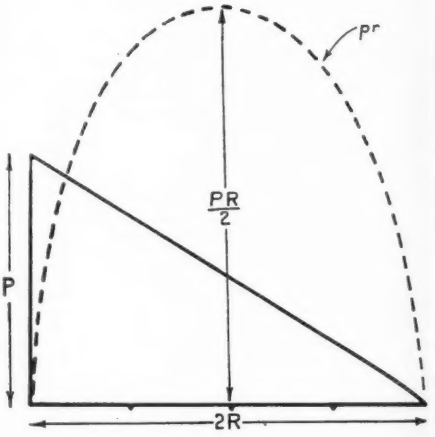

Fig. A3.

Therefore maximum revenue ton miles,

$$pr_{max} = \frac{PR}{4}$$

At any other point $pr = Pr\left(1 - \frac{r}{R}\right)$

There are two extreme methods of operating a tanker: in the first the air liner's flight is assumed to be over water or at least over country of such a nature that intermediate landing is not possible. In this case the tanker takes off from the air liner's aerodrome and, as the air liner must be able to return to its starting aerodrome should the refuelling be abortive, the optimum position for refuelling is $R/2$ miles from the starting point.

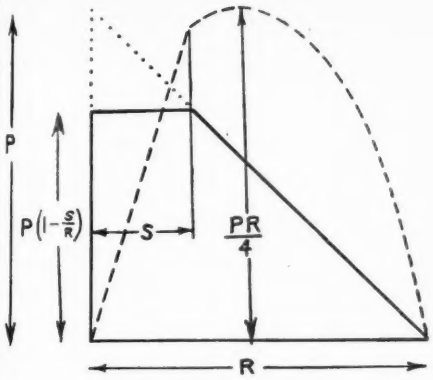

Fig. A4 (a).

Thus the maximum range with refuelling is increased by half to $3R/2$ and the payload versus range curve is as given in Fig. A2.

The payload for any range is

$$p=\frac{2P}{3R}\left(\frac{3R}{2}-r\right)=P\left(1-\frac{2r}{3R}\right).$$

The "pr" curve is a maximum at the mid-point, *i.e.* where $r=\frac{3R}{4}$ and $p=\frac{P}{2}$.

Therefore maximum revenue ton miles, $pr_{max}=\frac{3PR}{8}$, an increase of 50 per cent. over the unrefuelled value.

At any other point $pr=Pr\left(1-\frac{2r}{3R}\right)$.

In the second method of operation the tanker aerodrome and refuelling point are assumed to be at half the refuelled range. Thus refuelling in the air is merely substituted for a landing for refuelling by the air liner. This case, alone, might not be of great importance but, in practice, long air routes are generally partly over water and partly over land, so that a suitable tanker base may be available at some distance beyond the air liner's point of departure and thus provide a compromise between the two extreme cases.

In this method $\frac{p}{P}=\frac{2R-r}{2R}$ (*see* Fig. A3).

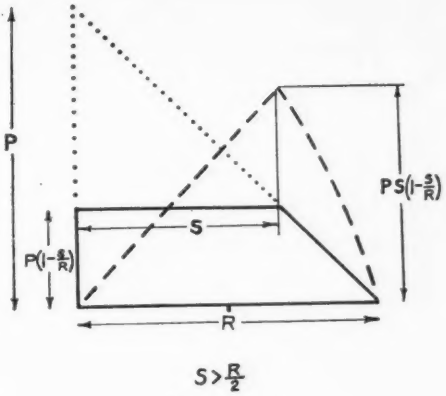

Fig. A4 (b).

Therefore $p=P\left(1-\frac{r}{2R}\right)$

and $pr=Pr\left(1-\frac{r}{2R}\right)$.

Both the maximum range and maximum value of "pr" are double those of the unrefuelled values,

$$pr_{max} \text{ being } \frac{PR}{2}.$$

In some current air liners the maximum payload is limited by fuselage capacity, in which case the payload curve becomes modified as in Fig. A4 (*a*) and (*b*).

If S = maximum range with capacity payload, in Fig. A4 (a) $S<\frac{R}{2}$ and in (b) $S>\frac{R}{2}$.

If $r>S$, $p=P\left(1-\frac{r}{R}\right)$; if $r<S$, $p=P\left(1-\frac{S}{R}\right)$ *i.e.* maximum payload.

In Fig. A4 (a):—

$$pr_{max}=\frac{PR}{4} \text{ (as in Fig. A1)}$$

In Fig. A4 (b):—

$$pr_{max}=\frac{P}{R}(R-S)\times S=PS\left(1-\frac{S}{R}\right)$$

In both cases, if $r>S$, $pr=Pr\left(1-\frac{r}{R}\right)$;

if $r<S$, $pr=Pr\left(1-\frac{S}{R}\right)$

With flight-refuelling at $\frac{1}{3}$ range, the diagrams become as shown in Figs. A5 (a) and (b).

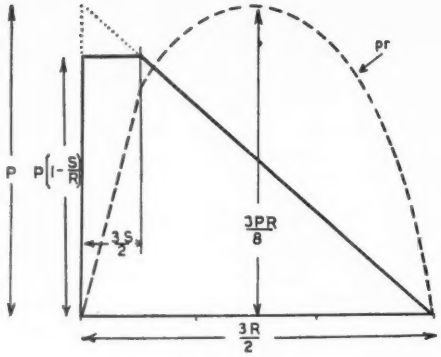

Fig. A5 (a).

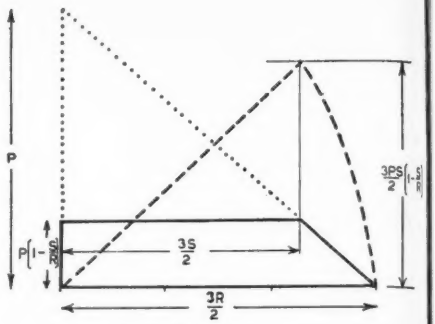

Fig. A5 (b).

In Fig. A5 (a):— $S < \frac{R}{2}$.

Then $pr_{max} = \frac{3PR}{8}$ (as in Fig. A2) .

In Fig. A5 (b):— $S > \frac{R}{2}$.

Then $pr_{max} = \frac{P}{R}(R-S) \times \frac{3S}{2} = \frac{3PS}{2}\left(1 - \frac{S}{R}\right)$.

In both cases,

if $r < \frac{3S}{2}$, $p = P\left(1 - \frac{S}{R}\right)$ *i.e.* maximum payload,

and $pr = Pr\left(1 - \frac{S}{R}\right)$.

If $r > \frac{3S}{2}$, $p = P\left(1 - \frac{r}{R}\right)$

and $pr = Pr\left(1 - \frac{r}{R}\right)$.

If the money value of revenue a ton mile is known, together with the operational cost of air liner and tanker, it becomes possible to make an assessment of potential profits.

Let x = revenue a payload ton mile
C_1 = air liner cost a mile, and
C_2 = tanker cost a mile

Then *without flight-refuelling*—

Revenue $= xPr\left(1 - \frac{r}{R}\right)$

Cost $= C_1 r$

and Profit $= xPr\left(1 - \frac{r}{R}\right) - C_1 r$.

With *flight-refuelling at ½ stage length*—

Revenue $= xPr\left(1 - \frac{2r}{3R}\right)$

Cost $= C_1 r + \frac{2}{3} C_2 r$, and

Profit $= xPr\left(1 - \frac{2r}{3r}\right) - \left(C_1 r + \frac{2}{3} C_2 r\right)$

With *flight-refuelling at ⅓rd stage length*—

Revenue $= xPr\left(1 - \frac{r}{2R}\right)$

Cost $= C_1 r + tC_2 r$,

where t = ratio $\frac{\text{tanker flight distance}}{\text{air liner flight distance}}$

and Profit $= xPr\left(1 - \frac{r}{2P}\right) - C_1 r - tC_2 R$.

Example—Consider the case of refuelling at ⅓rd distance and assume an air liner of 100,000 lb. gross weight with

Disposable load $P = 50{,}000$ lb. = 22 tons approx.

and $R = 6{,}000$ miles

The following cost factors may be assumed:—

x = £0.25 a revenue ton mile.
C_1 = £0.68 a mile.
C_2 = £0.40 a mile.

Figures for revenue, cost and profit are tabulated in Table A for a series of ranges and are shown plotted in Fig. A6, the revenue curves being dotted, the cost curves

TABLE A

r	*Without Flight-Refuelling*			*Flight-Refuelling at ⅓rd Range*			*Flight-Refuelling at ½ Range*		
Miles	*Revenue* £	*Cost* £	*Profit* £	*Revenue* £	*Cost* £	*Profit* £	*Revenue* £	*Cost* £	*Profit* £
1,000	4,582	680	3,902	4,888	947	3,941	5,050	880	4,170
2,000	7,333	1,360	5,973	8,555	1,894	6,661	9,166	1,560	7,606
3,000	8,250	2,040	6,210	11,000	2,838	8,162	12,375	2,240	10,135
4,000	7,333	2,720	4,613	12,222	3,784	8,438	14,666	2,920	11,746
5,000	4,582	3,400	1,182	12,222	4,730	7,492	16,044	3,600	12,444
6,000	0	4,080	−4,080	11,000	5,676	5,324	16,500	4,280	12,220
7,000				8,555	6,622	1,933	16,044	4,960	11,084
8,000				4,888	7,568	−2,680	14,666	5,640	9,026
9,000				0	14,190	−14,190	12,375	6,320	6,055
10,000							9,166	7,000	2,166
11,000							5,050	7,680	−2,630
12,000							0	8,360	−8,360

chain-dotted and the resultant profit curves being full lines. The diagram shows clearly how potential profits increase rapidly with flight-refuelling beyond a range of 2,000 still-air miles and how flight-refuelling enables profits to be made at ranges well in excess of the maximum profitable range under normal operation.

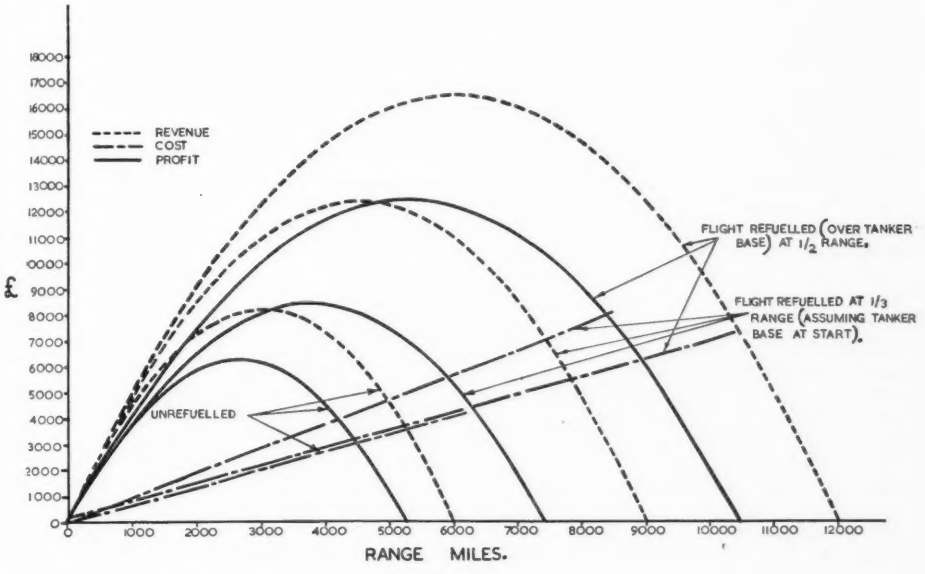

Fig. A6.
Revenue cost and profit with range. Unrefuelled and flight-refuelled.

ELEMENTARY ASPECTS OF TECHNICAL STATISTICS AND COMMON FALLACIES

WITH EXAMPLES ON MEASUREMENT OF AERO-ENGINE RELIABILITY

by

W. E. THORNTON-BRYAR, B.Sc.(Econ), A.I.S., F.S.S., A.R.Ae.S.

THE SUBJECT of statistics is so vast that many thousands of volumes have been written on it and it would be lunacy to try to give any complete outline in a brief paper. Even by confining the field to that range of data arising from aeronautical engineering the limit seems to recede into specialist abstractions rather than narrow as generality is jettisoned. At the outset it may be well to consider these apparent platitudes because many (most?) otherwise well-informed people are dogmatic in their belief that statistics are merely applied arithmetic. No doubt the same kind of thing was said before any distinction was drawn between a tally-clerk and a qualified accountant. The assertion contains too much fundamental truth for easy rebuttal: nevertheless there does exist both a science and an art in statistics, and arithmetic is only one important contribution to the exercise of either.

Ordinary engineering mathematics are not always enough, and many advanced researchers have to side-track from the ordinary calculus into the statistical variety. Atomic physics, plant genetics, gas turbulence, astronomy, and social sciences are examples of fields where theoretic work has moved from arithmetic through algebra and calculus into the statistically specialised branches of those subjects. Laplace and others blazed the trail in search of winning systems for gambling on dice, cards, and such games of chance. Their followers went in for large scale bookmaking and offered odds that specific persons would survive for a period of years. Success brought respectabilty and governments that frown on church bazaar raffles seriously propose to enter the business of insurance.

I venture to suggest that those whose knowledge of statistics is confined to the two expressions:—

(*a*) "There are lies, damned lies, and statistics" and

(*b*) "A statistician is one who distorts truth into a straight line from an unwarranted assumption to a foregone conclusion,"

should read one small, elementary, book on statistical method and glance through a more advanced book. It would then be possible for them to derive more benefit from the numerical reports which form the bases of many decisions and beliefs.

Among other things statistics is a powerful tool of large scale administration. Its importance grows as its use and abuse, scope and limitations, become better understood.

That great engineer Lord Kelvin said:—

"When you can measure what you are speaking about and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

In 1922, before consolidation of many industries by nationalisation had added point to his remarks, Professor R. A. Fisher said:—

"A quantity of data which, by its mere bulk, may be incapable of entering the mind is to be replaced by relatively few quantities which shall adequately represent the whole, or which in other words shall contain as much as possible, ideally the whole, of the relevant information contained in the original data."

Now I shall go on to explain how a much humbler person has tried to use statistical

Paper received April 1950.

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method to reduce a rather worrying and complicated mass of information into useful form. I shall be discursive to break up the monotony of the bits of arithmetic and because I want to stamp on a few fallacies as they crop up. It will also help me to skirt round bits of theory on which I fear my knowledge may be inadequate for deep penetration.

It seems fair to assume that whereas reliability is a first consideration among civilian users of aero-engines—particularly airlines—there is a shift of emphasis toward performance when military use is in view. Probably the genius for compromise is somewhat overworked when air crews' demands for the very latest, fastest, highest-powered aeroplanes come into conflict with the technicians' insistance on preliminary trials, tests, and development modifications before a design is approved and a contract placed.

Without entering into any controversy as to whether pilots bamboozle a government into buying equipment full of technical "bugs" or engineers withhold it from the users until it is out of date, it can be seen that there does exist a certain pressure acting to hurry acceptance. That those pressing for speedy introduction of untried novelties are the same people who will entrust their lives to them, adds force to their plea and reflects considerable credit on their devotion to the Service.

Apart from any demands for speedy conclusion of development tests, the prediction and simulation of every condition to which equipment will be subject in service is a task calling as much for prophets as technical scientists. No one dare deny the excellence of work done by inspired development engineers, but it remains true that the proof of the pudding is in the eating, and development work has to carry on after delivery to squadrons.

If the disadvantages of frequent modification provides cause for sadness in the hearts of technical officers, there is *per contra* a gleam of joy in the eye of the statistician who has a "sample population" big enough to support general conclusions about reliability.

I mean to labour this point a little because it is fundamental, and an example may help. Let us assume that 10 per cent. of "Whistler" engines are going to develop a certain serious defect after they enter the service. This is something we shall not know in advance. Assume that we select 10 engines for severe

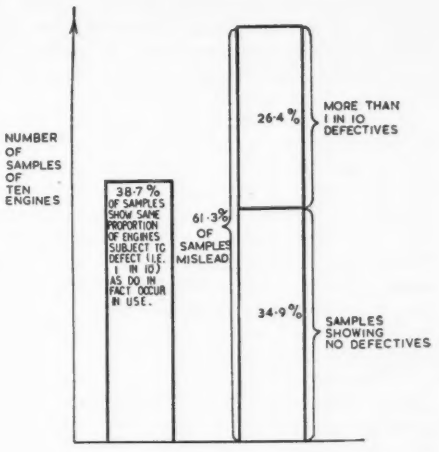

NUMBER OF SAMPLES OF TEN ENGINES
38·7 % OF SAMPLES SHOW SAME PROPORTION OF ENGINES SUBJECT TO DEFECT (I.E. 1 IN 10) AS DO IN FACT OCCUR IN USE.
61·3% OF SAMPLES MISLEAD
26·4 %
MORE THAN 1 IN 10 DEFECTIVES
34·9 %
SAMPLES SHOWING NO DEFECTIVES

Fig. 1.

Diagram to illustrate that random selection of a sample of ten engines, in order to examine them for a defect which occurs in 10 per cent of all engines, usually gives a misleading answer.

test. We hope that these engines will behave in just the same way, with the same proportion of defects, as would occur in, say, a thousand engines that will go into service. If we are wrong our conclusions and predictions will be wrong too. We are more likely to be wrong than right because the betting odds on exactly one defective engine turning up among the ten is a little worse than 6 to 4 against. There is about a 7 to 13 chance that no defective engines will turn up in the ten*.

*If probability of failure $= 10\% = p$ and probability of non-failure $= 90\% = q$ and the size of samples selected $= 10 = n$, then expansion of the binomial $(p+q)^n$ gives a probability distribution showing the chance (as a percentage of all possibilities) of various numbers of defective engines turning up among samples of ten selected at random.

Defective engines among the 10	Chance % of such an answer
0	34.9
1	38.7
2	19.4
3	5.7
4	1.1
5	Less than 0.2
6	Less than 0.1
7	Less than 0.001
8	Less than 0.000,1
9	Less than 0.000,001
10	Less than 0.000,000,1

This may be illustrated by Fig. 1, and in looking at it one should remember that the scale vertically is in numbers of samples if we assume 1,000 engines were selected in samples of ten entirely at random.

The point to note is that grumbles about defects of frequent occurrence are not always fair to manufacturers. A trouble that affects ten per cent of engines *might* have been picked up during tests of the first ten, but there is a fair chance it never came to light. Taking bigger samples, or more of them, is a good plan on paper, but this entails delay and expense which it is not easy to justify before anyone knows the engine is subject to a specific kind of trouble.

"To press on regardless" is also likely to prove expensive, and a judicious compromise has been developed. After the trials by manufacturers, purchasing agencies, and service representatives have revealed, and led to correction of, faults which manifest themselves among the first products, the engine begins to enter into large-scale production and use. At this point its life and behaviour begin to be recorded.

Two kinds of records are made. One comes into operation when a serious defect is found and the engine has to be replaced. This is a report on the history, modification state, and reason for removal, of the unserviceable engine. The second seeks a more positive kind of information so that failures may be compared with successes. It is not only necessary to know how many engines developed a certain defect, but in addition how many engines there were which did *not* develop it.

This leads logically to the next stage of enquiring whether a sudden change in the proportion of defects for a hundred engines in use is due to any such cause as a change in the amount of work done by the engines. Hence flying hours are taken into account.

Delving a little deeper we realise that it is not only the intensity of use which governs wear, tear, and failure. As with the miners (whose average age is about 10 years above the pre-war level), it takes more out of a power unit to deliver a certain quota when the effects of old age begin to show.

Obviously we cannot begin to collect information on a "stable" age distribution of engines as soon as they are delivered. We would like to know whether engines with less than 300 hours to their credit are very much more reliable than those with 500 or more. It would be nice to look at a curve and see that a certain type and mark ran efficiently up to 600 hours and then dropped badly in reliability. We could assess just when to call a halt for overhaul.

On the other hand if an unduly conservative estimate of reliability had been made we might be able to say "This engine has a high defect rate in its first hundred hours of life. Those that get through that period seem to settle down and improve in reliability. At the time they are removed for reconditioning they seem to be doing very well, so why not let them run a bit longer to see what happens?"

If by such means an addition of 10 per cent. could be made to lives between reconditioning a saving of the same order could be made in workshop cost, and provisioning of spare engines to bridge the gap of technical turn-round time could be reduced.

Achievement of this happy state of affairs takes time. Military aircraft must be kept in a condition of readiness for immediate and sustained action. They must all be used enough to keep them in trim, looked after enough to let them go a long time without much attention if need arose, and flown in rotation so that a "stagger" is achieved to allow a steady stream of aircraft to undergo periodic checks and replacements. Bunching is avoided to ensure both that a sufficient number of aircraft could meet emergency demands and to see that technical manpower is fully and steadily employed.

Re-arming squadrons is not an overnight affair. A stream of new equipment flows in from the Industry and builds up the flying stations. If we are waiting to see how well an engine survives we may watch carefully (and almost certainly impatiently) for the first dozen or two to reach a ripe old age.

If we assume an engine will fly 50 hours a month and 12 engines a month are delivered we shall probably find after a year that some of the original twelve delivered have been removed for a defect or strip examination and the remainder is a pretty small sample from which to generalise about the reliability of engines around 600 hours old.

Nevertheless we may have 120 engines in service if we allow for a few losses. Since all engines are "born young" the experience we can tabulate is much more reliable for early ages. Suppose we take intervals of 50 hours "life." Our "stagger" will show the last 12 arrivals in the 0 to 50 hour age-

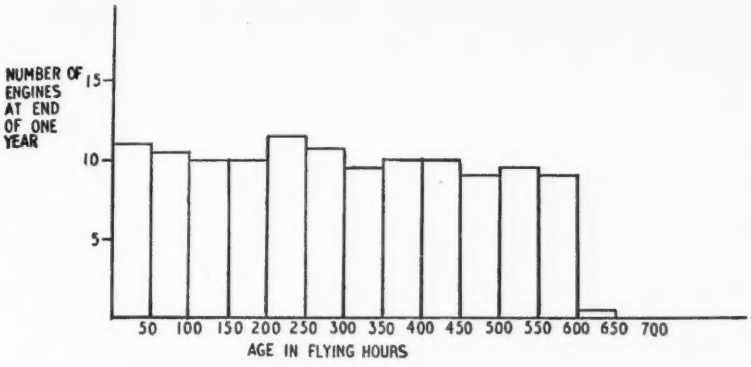


Fig. 2.

This demonstrates the age pattern of engines introduced at the rate of 12 a month and flying at a rate of 50 hours a month after one year.

interval (if none get lost on the way through accident or other cause) and there would be 12 in each successive group, but in fact we would expect some such picture as in Fig. 2.

It will be seen that the ideal stagger is not always achieved perfectly, for example in the 200 to 250 hour division there are more engines than were supplied when that batch began its life. It may mean a laggard or a thruster, perhaps both, and it may mean several if the original 12 lost one or two on their way to 200 hours. In general the expected effect of "ten little nigger boys" is discernible. The longer they are exposed to risk the more there are lost.

From Fig. 3 we can see that although a good deal of information about reliability of engines in their first few hundred hours has been accumulating, it is still sparse about the 600 hour mark. Naturally it is this end of the scale in which we are mainly interested. At some stage in life every engine is stripped and rebuilt. That age is economically and strategically important, and one of our main objects is to throw light on the condition of engines as they approach critical age points.

One thing examination of Fig. 3 should do is explode the widespread assumption that a year after announcement that a new engine will be coming into service a complete statistical picture is available. In fact, the data on engines around 600 hours is as inconclusive as that discussed in the sampling for test mentioned earlier.

Nevertheless the numbers of engines that have passed through the early groups have given samples of 144 downwards, and in the course of the next few months the whole picture will move a few spaces higher in the direction of seniority. The larger samples can be shown to provide more accurate estimates than the smaller ones, and although the pattern of experience will still have a downward trend the aged engines ultimately will provide an accumulation of hours on which computation may be based.

Another common mistake is that of considering an average (arithmetic mean) to be invariably a good planning figure. It takes scarcely a moment's thought to realise that it is a figure as much exceeded as unreached by the numbers it is meant to represent. If we took the average age of visitors to a certain park we should not be surprised to find it was 30 years. But if 10 Chelsea Pensioners dozed in the shade while 20 kindergarten children romped in the sandpit, it could give this result while no-one between the ages of 10 years and 60 was present. Arithmetic averages are useful, but one should select another average (median, mode, geometric mean, harmonic, and the like) if it is better suited to the data, and should always remember that not all the figures are close to the average of the group.

To take an "average life attained" figure on the basis of Fig. 3 would be to invite error. Another kind of average, the defects for 1,000 hours, would be not quite so bad as the last, but still liable to lead to trouble if it were used for any kind of future planning.

It is this kind of amateur statistics that has led intelligent staff officers to rely on inspired

guesses and subjective impressions (to the considerable benefit of their services). With strained resources in finance and skilled manpower, more accurate measurements are needed than ever before, and a judicious combination of suitable information with practical experience has led to some quite remarkable achievements in several Commands of the Royal Air Force.

Let us assume that at the stage reached in Fig. 3, or a little later, there comes a decision to expand the number of aircraft which use engines of the "Whistler" type, but which can also be equipped with "Rattlers." Reliability will be a criterion for decision, and by calculating the age-specific defect rates for each engine and applying them to an artificially stabilised (imaginary) population of engines, a comparison can be drawn. This kind of population may require a word of explanation.

In human measurements for insurance purposes the betting odds that a person aged some number of years will live for an additional "ration" of years is calculated from the risks he runs at present age to that age plus one, from plus one to plus two, and so on. If someone attempted to insure all the men in his factory, the underwriters would immediately want to know the ages of the men.

If we assume that he also insured his women operatives he would probably find a much lower premium quoted. This could be for either or both of two reasons:—

(*a*) The age structure of the women was generally such that they were about to pass through years of low risk, and/or

(*b*) The longevity of women was greater than that of men, *i.e.* their mortality rate was lower in most age groups.

It would be wide of the mark to suggest that women were always better risks than men if these men were mainly senior technicians, supervisors, and the like, of mature years, while the women were youngsters filling in a few years between school and marriage.

This is a common fault in aero-engine life assessment. An actual population of young engines has its "average expectation of life" calculated and compared with that of an engine which has been long in use. No allowance has been made for the unbalance of the two samples.

In population studies this kind of difficulty is dealt with by "standardising" the death-rate. Each year the proportion of survivors

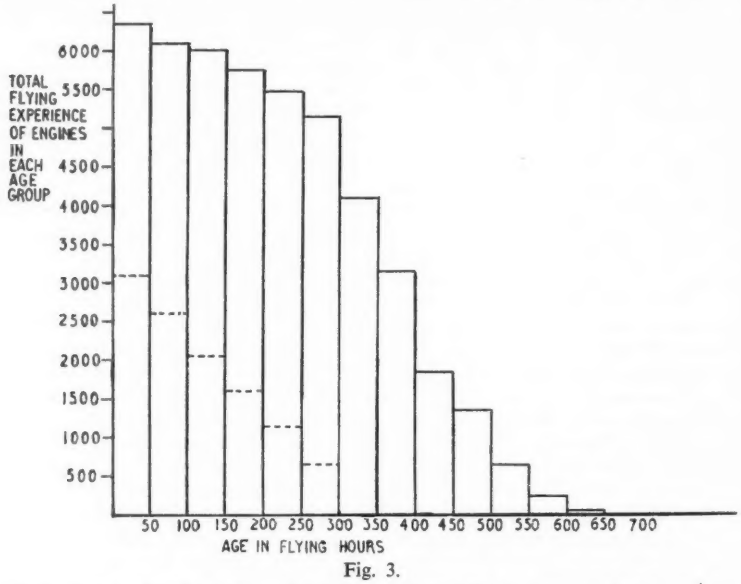


Fig. 3.

Indicating roughly the pattern of experience of reliability in young and older engines on assumptions similar to those of Fig. 2. The dotted line suggests the rough pattern six months earlier.

to deaths is worked out, and the proportions are applied to a population whose age structure is quite different from the present one. In fact it is a population that existed early in the century, but by applying current age-specific mortality rates each year to this historic cohort it is possible to see whether survival is improving, "other things being equal."

Something of this kind must obviously be done if we are to isolate the amount of trouble caused by classification into human sex (or engine type) from the quite different trouble originating in differences of age. As an illustration of the fallacy of using "straight averages" a glance at Fig. 4 will show how the number of engines per month removed from airframes for overhaul will vary. This calculation is based on figures provided by the U.S.A.A.F. and published in the American Statistical Association's Journal, and relies on an assumption that 80 engines begin life and are replaced whenever one is removed for overhaul or otherwise lost from the aircraft. It is assumed that each engine flies 44 hours a month and is overhauled at 300 hourly intervals, if no prior cause for overhaul (defect) is found.

With this theoretic population of 80 engines, and with the rather improbable assumption that each one flies exactly as much as any other, all those which do not fall by the wayside become due for periodic overhaul about the same time. They are replaced, and now we have a population which is mainly new but contains a few veterans which were replacements of the losses in the first month or two. The proportion of veterans to replacement engines increases in each 300 hour cycle until we reach a comparatively "stable" population with fairly steady "arisings" of engines for overhaul after about five years.

This is rather a long time to wait for information in a fast-moving force. The anwer seems to be similar to that used in human life tables, *i.e.* the establishment of an arbitrary "standard population" to which rates can be applied.

Getting back to our "Whistlers" and "Rattlers" we are going to throw in a new complication. We shall assume the "Rattler" is an engine which has been in use some time and experience, inspired guesswork, plus a few tests, have led those responsible for such decisions to lay down an interval of 600

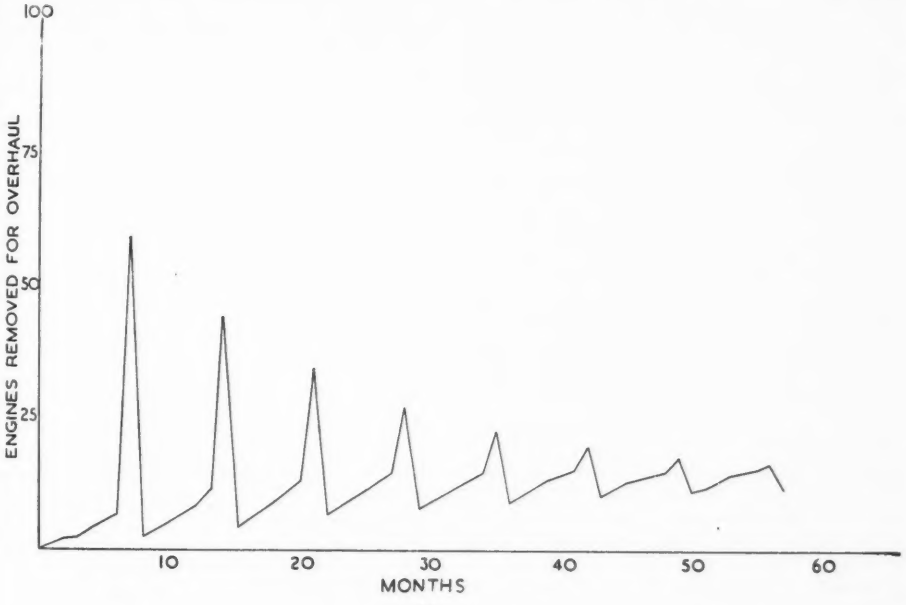


Fig. 4.

Monthly numbers of engines requiring overhaul for 80 engines kept in use at 44 hours' flying a month with all losses replaced by new engines.

hours between overhauls. This is the "arbitrary overhaul life" of the engine. On the other hand the "Whistler" is a new, higher powered, faster engine. There exists some suspicion as to its reliability after prolonged and severe use in adverse service conditions. Its life is fixed at 300 hours, subject to change in the light of experience.

It is almost as if we were asked to assess mortality figures when every male was shot at the age of 60 and every female at the age of 30. Without going into the merits of this suggestion, it can be seen that ceilings are imposed on the average expectations of life, which certainly cannot exceed the arbitrary maxima.

There are a few fallacies of statistical manipulation which are far more common than they should be, and it may be best to illustrate these with examples. The examples are carefully "cooked" so that no senior officer will recognise that I venture to correct him.

Let us assume that for a year or two the officers of a certain force have been discussing the merits, and probable date of delivery, of the "Whistler." To simplify the example let us say 80 engines come into service after this period of two years. Already the equipment branches have begun enquiries as to the permissible running hours between overhauls, the number of spare engines required to keep 80 in serviceable use, and the turn-round time on overhaul. Estimates based on analogy with existing engines are given by the engineers.

The engineers wish to know how much trouble the engine will give in service. The equippers impatiently await information based on service experience and conditions rather than on inspired guesswork.

Three or four months after entry of the new engine into service the statistics branch begins to receive enquiries, and it replies that no engine has yet flown more than 150 hours and calculation would be premature.

When six or seven months' experience has been gained and the information has been gathered, an enquiry may be received as to what percentage of engines in use are lost to the squadrons a month.

Now the number in use was kept constant at 80. Whenever an engine had to be removed the equippers produced a new one. There were 41 engines replaced. It is therefore quite simple to calculate 41 is about 51 per cent. of 80, and since these replacements occurred over six months the rate for each month is one sixth of 51 per cent., *i.e.* about 8.55 per cent. Such an answer might be given.

The computor of the percentage then relaxes after the pressure of urgency and notices that, in fact, there were more than 80 engines exposed to the risk of requiring overhaul. The 41 replacement engines have been presumed (by our calculation) to trickle in at the rate of 8.55 per cent. a month; a little more than eight engines a month. Altogether 121 engines were in use at one time or another in the six months.

What was the percentage failure rate a month on this basis? Obviously 41 as a percentage of 121 divided by six, and

$$\frac{41}{121} \times \frac{100}{6} = 5.65 \text{ per cent. a month.}$$

This looks a little better. The reserve of spare engines can be 3 per cent. lower than we thought, and the engineers will be a little happier at less frequent engine changes, while the air crews will rejoice that fewer aircraft will be unavailable because engines must be changed.

If someone should later mention that "Whistlers" will be flying double their usual monthly number of hours soon because of new exercises or operational requirements, we may pause to consider what effect this is likely to have on the number of replacement engines required. Double? That of course is the ratio of increase, but it is essential to have enough for this particular purpose and we cannot afford a surplus. Is this six months' average percentage perfectly correct every month, or is it the average of several much higher and lower figures? As a statistician would say, "What is the dispersion about the mean?" But here we assume that statistical training and jargon are confined to a very few people involved in the development and use of the figures.

A form of question is generally posed as, "What is the average number of hours each engine attains before it is removed for overhaul?" If we knew it to be x hours we have only to divide the total of planned flying hours by x to get the probable number of replacements needed.

We can assume that about 23,000 hours were flown by all the engines in use during the six months. Dividing this among the 121 we can say that the average hours flown by the engines in use was 190 hours each. It is not difficult to find examples where such

figures have been thoughtlessly provided in response to a request for "average hours flown for an engine in use" and uncritically accepted as a planning figure for the "average expectation of life."

A moment's thought shows that this figure would only be valid if every one of the 80 serviceable engines in use at the end of the period were to develop a need for overhaul before its next hour of flying life.

It may seem paradoxical that the average expectation of life can be derived only from study of information on persons or subjects whose life has ended. It is only then that we can depend on them not to make our figures useless by living some more hours beyond those we have on record.

Accepting this correction let us look into the life attained by the engines which were removed. There were 41 of them. How shall we assess their average attainment of life, or, to put it another way, their mean age at removal? We cannot answer this without obtaining more information. But first a necessary digression has to be made.

One aspect of statistical craftsmanship is revealed by an ability to obtain (*a*) no more than is necessary, and (*b*) no less than is sufficient, data for a specific purpose. This may seem a shocking statement to those whose idea of statistics is an exhaustive list of every numerically describable quantity, quality, and attribute of some collection of study-material, but it is nevertheless a fact of experience. It is perhaps true that research into subjects which seem fascinating, but quite useless, may sometimes provide a key to understanding, and open up astonishing possibilities. Physical science abounds with examples of human profit from what once seemed merely academically amusing investigations. This is work for the universities. With limited resources in man-power, brain-power, and education it becomes necessary to split our forces into those who seek knowledge for its own sake and those who seek knowledge for immediate use.

In the simple fields of chemistry and physics there is a readily observable pattern of repetitive phenomena. We expect, and generally obtain, closely similar results from similar experiments, and for the most part the language of pure mathematics can cover the needs for description. But sometimes the results of experiments are contradictory and it may be found that some factor beyond the knowledge and control of the experimenter is causing changes which could not be explained. Hypotheses are discarded and "Scientific Laws" are discredited unless, or until, the cause of variation is discovered.

In the Royal Air Force there is little chance to work in laboratory conditions and many influential factors such as weather, radio reception conditions, health of personnel and availability of certain resources are not immediately controllable nor accurately predictable. It is often a case of gathering empiric information to see if it supports or demolishes some theory or other. One is forced to the "chuck them in and see if they can swim" kind of investigation, because to check exhaustively every possible factor and to tackle the prodigious task of analysing the results would surely mean that most of the working life of airmen would be devoted to recording what happened to equipment and to themselves. We cannot afford to let the tail wag the dog. Equally we must not cut off the tail that balances the dog. This digression is intended to silence those who might suggest that every engine should be given individual treatment as it is admitted to the collection of basic statistical data. In fact, the reports are demanded from busy technical men who are often living and working in difficult conditions and who already have more paper-work than they feel is necessary. To increase the load beyond reason is tantamount to inviting inaccuracy, unpunctuality and exasperation which injures morale.

Each Command is asked to provide information on a selected array of types and marks of engines, and it reports at quarterly intervals. Precision of recording is required only within certain limits, and reports show numbers of engines lost between the ages of 0 and 50 hours and so on, in groups of hours. Thus instead of reporting the hours and minutes flown by each of 41 engines we merely require the entry of the number lost against each age-group as shown in Table I.

TABLE I

HOURS RUN	ENGINES LOST BY UNIT
0- 50	5
51-100	3
101-150	3
121-200	3
201-250	2
251-300	25

Now we know the engines all began as new, and if we assume the engines are evenly

distributed about the middle of their age groups we can calculate as shown in Table II.

TABLE II

AVERAGE HOURS RUN	ENGINES	TOTAL HOURS (PRODUCT OF LAST 2 COLUMNS)
25	5	125
75	3	225
125	3	375
175	3	525
225	2	450
275	25	6,875
	41	8,575

Therefore we can say that when 41 engines required overhaul they had a total of 8,575 hours to their credit, or that they had an average life of 209.1 hours. This is an improvement on the 190 hours previously assessed.

By a little simple arithmetic we may guess how many flying hours the 80 remaining engines will have if they behave like the first 41. All the 121 engines flew 22,925 hours, and if we subtract the 8,575 flown by the removed engines it leaves 14,350 hours to the credit of our 80 remaining. Their average attained life is nearly 176 hours, which suggests that in the next month all the 80 will require overhaul and the average of 44 hours for an aircraft a month will not be attained by this 80, for they have only an average of 33 hours' life left.

This is a severe and sudden demand for complete replacement of every "Whistler" in use in a very short period. But we are talking about averages. Perhaps some of the engines will require overhaul in the next 10 or 20 hours, while others reach 50 or 60 more hours. This matter of dispersion about the average is becoming important. Must we buy 80 new engines to keep our aircraft available, or can we press on with overhaul of the 41 in the hope that only half the 80 in use will need replacement before the next 44 hours have been flown?

Perhaps it depends on how many of the 80 are nearly at the limit of 300 hours, and how many are fairly new. We will ask for information about the ages of the 80 as well as the 41. Our information now reads as in Table III.

We notice that someone has decided to let an engine run beyond 300 hours (possibly to see the result of an extra few hours on the engine). We also notice that 60 engines are more than half-way to the arbitrary end of life, and only 20 have flown less than 150 hours. This looks less promising than we might have hoped. The engines are elderly for the most part.

A glance at the column headed "Lost" shows that more engines were withdrawn from use during the first 50 hours of flying than at any other age before 300 hours. Naturally this does not mean that the first 50 hours are the more risky, because many more engines were exposed to risk in that group than in any other. Since every engine began in the 0 to 50 group, the entire 121 engines were in that age-group at one time or another. By contrast, only 32 engines have ever been exposed to risk in the 251-300 hour age-group. It seems a good plan to find the relationship between loss and survival in each 50 hours of life so that some risk assessment can be calculated.

TABLE III

	ENGINES	
HOURS RUN	LOST	LEFT
0- 50	5	2
-100	3	3
-150	3	15
-200	3	34
-250	2	19
-300	25	6
-350	0	1
	41	80

The fact that we have decided to use age as a criterion reveals an implicit assumption that there is some functional relationship between hours of flying use and the arising of engines requiring overhaul. This is one reason for calculating our rates of loss to survival in the form of "x engines for a thousand flying hours in age group y." A second reason is that this particular expression of the rate is familiar to users and fits into the methods of provision planning. A third reason is that a little refinement in accuracy of the rates can be obtained in our calculation if we make certain plausible assumptions about the symmetry of the ages of engines in an age group around the middle of the group.

We now wish to see what the loss rate for 1,000 hours is in each age group. We know how many were lost so we adopt a little convention that all engines in the 0-50 hour group have flown 25 hours exactly, and we credit them with that achievement imme-

diately they enter the group. They are credited with no more until they can show that they have another 25 hours behind them, *i.e.* when they enter the 51 to 100 hour group. On the occurrence of "crossing the border" 25 hours are credited to experience in the junior group (giving the correct total of 50) and 25 hours in the newly-entered group to bring the engine to mid-group. In effect, we only record when the engines are "on the rungs of the ladder," although we know they may be between rungs at the time our periodic check provides a snapshot of the age distribution. This is a legitimate statistical trick. Now we will do it (Table IV).

TABLE IV

HOURS PER AGE-GROUP CALCULATION

(*a*) AGE GROUP	(*b*) NUMBER ENTERED GROUP	(*c*) NUMBER LEFT AND LOST IN GROUP	(*d*) SUM OF GROUP ENTRIES AND EXITS	(*e*) GROUP FLYING HOURS
0- 50	121	7	235	5,875
51-100	114	6	222	5,550
101-150	108	18	198	4,950
151-200	90	37	143	3,575
201-250	53	21	85	2,125
251-300	32	31	33	825
301-350	1	1	1	25

The computation follows this order. Columns (*a*) and (*c*) are filled from the report, as well as the first line of column (*b*). Subtracting the 7 engines left and lost from the 121 we begin with, *i.e.* (*b*)-(*c*) we have 114 engines which left the group in good order. They entered the next senior age group and are recorded in line 2 of column (*b*). This procedure is repeated line by line until column (*b*) is completed.

To obtain data for column (*d*) we add together the number of engines entering the age-group and the number which reached the next higher age group. We credit each of these events with 25 hours of flying and complete column (*e*), *i.e.* 25 (*d*)=(*e*).

Now to relate the losses to the risk exposure (Table V).

What does this suggest? If we disregard for a moment the first and last two age-groups we obtain some support for the theory that age and wear contribute to loss,

TABLE V

AGE SPECIFIC LOSS RATES CALCULATION

AGE	LOSSES	HOURS	LOSSES FOR 1,000 HOURS
0- 50	5	25	0
-100	3	825	30.303
-150	3	2,125	.941
-200	3	3,575	.839
-250	2	4,950	.606
-300	25	5,550	.541
-350	0	5,875	.851

because the loss rate rises with age. But what is the explanation of the very high initial loss rate in the first group and the penultimate one? The last group has no loss rate simply because the data are not sufficient for calculation.

It is fairly obvious that the loss rate of 30.303 is influenced by the arbitrary removal of engines which have not suffered a defect warranting their premature overhaul. The rates we have calculated provide a rough basis of fact for calculation of future replacement needs if we know two things:—

(*a*) What is the age distribution in groups at the start of our calculations, and

(*b*) How much will the engines fly in the period forecast.

There is, however, this caveat. In the early groups we have about seven times more experience behind our rate calculation than in the 251-300 group. We should be surprised if an additional six months of experience did not cause us to revise our rates. Probably the high initial loss rate was due to "teething-trouble" and results may improve.

Now this is all very well for the calculation of equipment provisioning for the future, but the engineers naturally enquire, "Can these figures be used to guide us in our hope that the arbitrary life may be safely extended?" and "How many engines in each group were overhauled because of technical failure and how many because of other considerations?" These are fair questions, but the answer is not known and cannot be found unless we can discover the reasons for the losses. Hence we are driven to ask reporters for more information, but again we try to keep it to a minimum.

We find that the main reasons for removal of engines for overhaul are:—

(*a*) Mechanical defects of the engine itself.

(*b*) Defects due to installations and services which are not strictly part of the engine

(*e.g.* broken oil pipes leading from the airframe).

(*c*) Other causes (such as minor accidents and damage) which are judged to warrant premature overhaul as an immediate necessity, or as a sensible precaution.

(*d*) Written-off engines, either because of damage beyond repair or the aircraft's becoming "missing."

(*e*) Time-expired engines which are removed for no other reason than the consumption of their arbitrary life's flying time.

(*f*) Other withdrawals of a miscellaneous kind, including special strip examinations for checking purposes, experimental work, changes of mark by modification, and transfers of aircraft with engines to other theatres.

Our long-suffering friends tell us that the losses in our list can be classified as in Table VI, so we break up our rates to give them by cause of loss.

Technicians concerned with engines as such can now form some idea of the reliability of the engines *ceteris paribus*. This is all very well, but do the rates show significant differences in reliability as a function of age? Not very well now, because there seems to be no linear, or nearly linear, trend of higher loss as age advances. We suspect these figures are a little unreliable and taking thought we realise that we have tried to divide 41 losses among 36 different age-and-cause classes. The result is that we have very few occurrences from which to draw conclusions. The data are insufficient for statistical treatment in such detailed breakdown. If there had been 410 or 4,100 losses we might have felt more confident that bits of unusual bad and good luck would cancel out to some extent and any remaining chance bias would be a tiny error as a proportion of the answer.

TABLE VI

REMOVALS BY CAUSE

Age	*Mechanical defect*	*Installation defect*	*Other causes*	*Write off*	*Time expired*	*Other withdrawals*	*Total losses*
0- 50	3	—	—	1	—	1	5
-100	2	1	—	—	—	—	3
-150	1	—	1	1	—	—	3
-200	2	—	1	—	—	—	2
-250	1	—	—	—	—	1	2
-300	0	—	—	—	25	—	7

TABLE VII

REMOVAL RATES PER 1,000 HOURS BY CAUSE

Age	*Mechanical defect*	*Installation defect*	*Other causes*	*Write off*	*Time expired*	*Other withdrawals*	*Total losses*
0- 50	0.51	—	—	0.17	—	0.17	0.85
-100	0.36	0.18	—	—	—	—	0.54
-150	0.20	—	0.20	0.20	—	—	0.61
-200	0.56	—	0.28	—	—	—	0.84
-250	0 47	—	—	—	—	0.47	0.94
-300	0	—	—	—	30.303	—	30.30

The consequences of these reflections is that the statistical department, if hard enough pressed, will reveal the figures but will give many reasons to indicate their unreliability and the increase of unreliability due to poverty of experience in the older aged engines. Nevertheless the rough order of magnitude (such as whether loss rates are nearer 0.005 or 5.000 for 1,000 hours) sometimes helps planners in cases where completely new equipment (*e.g.* jet engines) replaces that with which analogy is known to be difficult of justification.

The statistician will await the accumulation of records and experience and calculate three sets of information. One will be the changes in rates as time (sheer calendar time —not flying hours alone), passes. This is because the technical competence in maintaining equipment increases with experience, the handling of equipment by users tends to become more suited to its peculiarities, and improvements to the engine by modification may aid its longevity. A second will be the accumulated total of defects and hours and the rates calculated from this maximum record. This will be the calculation for general use. The third will be the latest reported defects and their rate calculation.

Here, then, is the raw material which may be used to compare the reliability of one engine with another, help to assess the age at which engines should be withdrawn for overhaul, and to give the financial and provisioning branches some planning factors for their future purchases, air vote calculations, repair contracts and the like.

It is notable that since there are six classes of loss listed, the defect rates which could be provided are more than 5,000 according to what combination of losses is required for the purpose. Hence branches providing rates of this kind must make pedantic enquiry as to what is meant when the "Engine Loss Rate" is requested.

Once we have enough material recorded to feel that our rates are fairly reliable, we can work out how many engines would be lost in each age group if, say 100 new ones were

delivered each month. Taking the number of survivors in each group we can calculate the hours they would run in the group, and their loss rate, from any specific selection from the six classified causes. Adjustments must be made to see that loss rates are not applied twice. From this "stable" population of engines the age specific loss rates can be "weighted" to give overall (age-groups) defect rates and the average expectation of life for the particular engine.

Some of these calculations can be put to a different use. Suppose that technicians become disturbed at the frequency of occurrence of some breakdown which may not necessarily call for immediate and complete overhaul of the engine, nor even its removal from the airframe. Nevertheless it is a defect which often stops an aircraft flying at a time when it is needed. A modification may be very expensive. Is the modification justifiable?

From defect reports we can ascertain the dates of the defects and the hours flown by the engines at the times the trouble developed. Relating this to the total hours flown by all such engines in that age group up to that time, we can say whether it happens only late or early in engine life, and whether it occurs only once in 10,000 or once in 700 hours. This, related to cost of flying hours lost, man-hours in rectification and such expenses, can help to give an economic criterion as to the value of the modification to be set against its cost of purchase and incorporation. Of course, the economic is not the only standard, since tactical and safety considerations may make very infrequent defects worthy of great expenditure. Nevertheless it has become important to make every pound of the Air Vote work much harder than it used to do, so we must at least know what savings and costs are involved in any contemplated action.

(*Correspondence is invited on this paper.*— Editor)

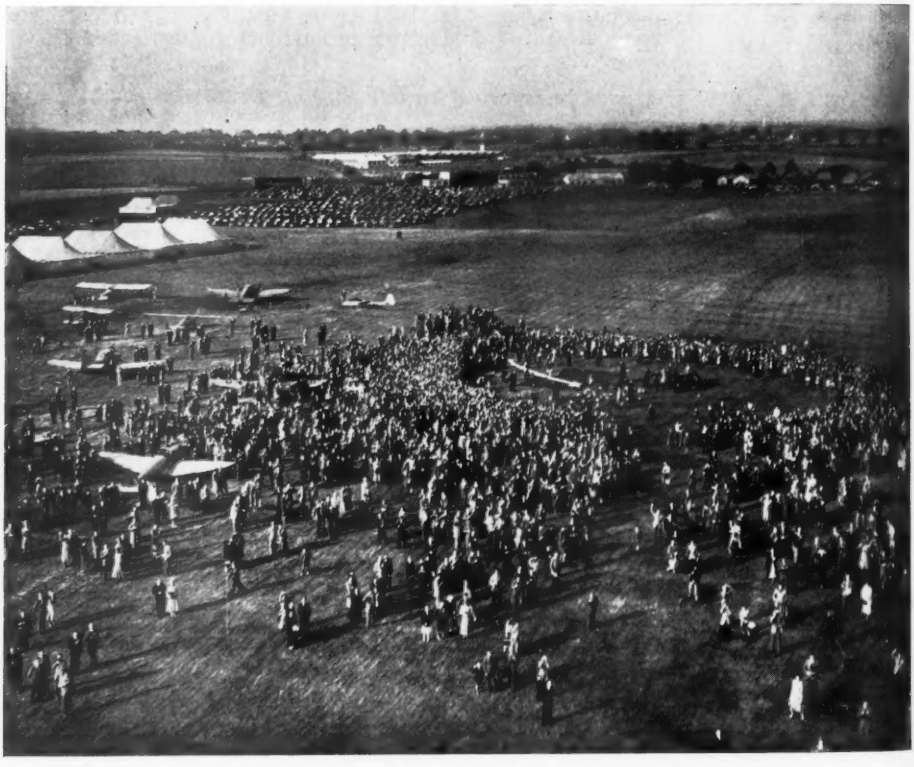
THE 1950 GARDEN PARTY

THE 1950 Garden Party of the Society was held at White Waltham Aerodrome near Maidenhead on Sunday 14th May 1950.

Altogether some 5,000 members and their guests were present, many of whom arrived by air, including a number from abroad.

Members and their guests were received by the President, Sir John S. Buchanan, C.B.E., F.R.Ae.S., and Lady Buchanan.

The Society is particularly indebted to Sir Richard Fairey, Honorary Fellow, Past-President of the Society, and to the Directors and Staff of the Fairey Aviation Co. Ltd. for their assistance in the general organisation of, and arrangements for, the Garden Party and to the Ministry of Supply for kind permission to use the aerodrome. The Council also thank the West London Aero Club and the Reserve Command, Royal Air Force at White Waltham, for their co-operation.



White Waltham Aerodrome photographed from the balloon just after it had started on its 20 mile flight at the end of the Garden Party. The balloon was piloted by M. Charles Dollfus and his passengers were Mrs. J. L. Pritchard, Mr. Peter Masefield and Mr. Charles Brown, who took the photograph.

Group Captain R. G. Slade was Officer Commanding Flying and the Council pay special tribute to him, Mr. S. M. Moseley and Mr. V. G. Robb, for their work in connection with the flying programme and to Lt. Cdr. B. J. Hurren and Mr. C. S. Watkinson (de Havilland Engine Co. Ltd.) who gave a broadcast description of the events during the afternoon.

The Council also wish to thank the Ministries of Supply and Civil Aviation, the Air Ministry and the London Air Traffic Control Organisation for their assistance.

For the first time, the Branches of the Society played a prominent part in the Garden Party and the Council pay a warm tribute to all Branches for their work in connection with the model aircraft display. They thank particularly the Hatfield, Luton, Reading and Weybridge Branches for their help not only in providing models but for the assistance of their members throughout the afternoon, and the Portsmouth Branch for the model aircraft and the demonstrations of Control-line flying, which aroused much interest and amusement. The Council also wish to thank Mr. F. J. Camm for lending the model which first won the Wakefield Cup.

The Branches of the Society and the aircraft firms that made possible the remarkable collection of models are as follows:—

Branches

Belfast
Birmingham
Bristol
Brough
Coventry
Glasgow
Gloucester and Cheltenham
Hatfield
Isle of Wight
Leicester
Luton
Manchester
Portsmouth
Preston
Reading
Southampton
Weybridge
Yeovil

Aircraft Firms

Air Service Training Ltd.
Airspeed Ltd.
Sir W. G. Armstrong Whitworth Aircraft Ltd.
Auster Aircraft Ltd.
Blackburn & General Aircraft Co. Ltd.
Boulton Paul Ltd.
Bristol Aeroplane Co. Ltd.
Cierva Autogiro Co. Ltd.
English Electric Co. Ltd.
Fairey Aviation Co. Ltd.
Gloster Aircraft Ltd.
Handley Page (Reading) Ltd.
Handley Page Ltd.
de Havilland Aircraft Co. Ltd.
Hawker Aircraft Ltd.
Humber Ltd.
Kelvin & Hughes Ltd.
Percival Aircraft Ltd.
A. V. Roe & Co. Ltd.
Saunders-Roe Ltd.
Scottish Aviation Ltd.
Short Brothers & Harland Ltd.
Slingsby Sailplanes Ltd.
Vickers-Armstrongs (Supermarine) Ltd.
Vickers-Armstrongs Ltd.
Westland Aircraft Ltd.

The Flying Programme which began at 3 p.m. was as follows:—

Aircraft	*Owner*	*Pilot*
Chrislea-Skyjeep, G-AKVS	Chrislea Aircraft Co. Ltd.	H. G. Handley
Zaunkoenig, G-ALVA	Ultra Light Aircraft Association	J. Fricker
Olympia Glider, G-ALJZ	Surrey Gliding Club	Lorne Welch
Hawker Hart, G-ABMR	Hawker Aircraft Ltd.	G. F. Bullen
Sopwith Pup	Shuttleworth Collection	A. H. Wheeler
Hawker Hurricane, PZ.865	Hawker Aircraft Ltd.	T. S. Wade
Nord Stampe Exhibition Squadron		i/c Commandant Perrier
Fairey Junior, OO-TIT	Fairey Aviation Co. Ltd.	J. O. Mathews
Auster Autocrat (Goodyear Undercarriage), G-AJIZ	Auster Aircraft Ltd.	R. Porteous
Comper Swift, G-ACTF	R. E. Clear	R. E. Clear
Westland Sikorsky, S.51	Westland Aircraft Ltd.	K. Reed
Ultra Light Aircraft Circus:		
Chilton DW/1, G-AFGI	J. S. Sproule	J. S. Sproule
Slingsby Motor Tutor	Slingsby Sailplanes Ltd.	J. Rushton
Tipsy "B," G-AISA	Cardiff Ultra Light Aeroplane Club	G. A. J. Goodheart
Aeronca, G-AEVS	T. E. Scott-Chard	T. E. Scott-Chard
B.A.C. Drone, G-ADPJ	A. C. Waterhouse	A. C. Waterhouse
de Havilland Chipmunk, G-ALWB	de Havilland Aircraft Co. Ltd.	P. Fillingham
Fokker S.12, PH-NDC	Royal Dutch Aircraft Factories Fokker, Amsterdam	M. Bugerhout
Lunak L.107 Sailplane, G-ALSI	L. C. Marmol	L. C. Marmol
Hawker Cygnet, G-EBMB	Hawker Aircraft Ltd.	F. Murphy
Hurel-Dubois H.D. 10, F-WFAN	Avions Hurel-Dubois, Paris	M. Dellys
Fouga Cyclone (Sylphe)	Establissements Fouga et Cie (Castel-Mauboussin)	L. Bourrieau
Blackburn Monoplane	Blackburn & General Aircraft Co. Ltd.	R. F. Martin
The Balloon	Charles Dollfus	Charles Doilfus

Control-Line Flying by the Portsmouth Branch of the Society was demonstrated at intervals during the afternoon.

In addition to the many visiting aircraft the following aircraft were shown:—

Type	*Owner*
Auster Tug	Mrs. Ann Douglas
Auster Crop Duster J/5	Auster Aircraft Co. Ltd.
B.A. Swallow Mk. II	G. H. Forsaith
Beechcraft C.45 Expeditor	U.S. Air Attaché
Benes-Mraz BE-550 BIBI	H. Clive-Smith
Benes-Mraz Sokol M.I.C. Falcon	Group Captain G. Shaw
Blackburn Monoplane	Blackburn & General Aircraft Co. Ltd.
Blackburn B.2	Blackburn & General Aircraft Co. Ltd.
Bleriot Monoplane	Shuttleworth Collection, Warden Aviation Co.
Cessna C.34	R. E. Dewhurst
Chrislea C.H. 3 Super Ace	D. Lowry
Comper Swift	A. L. Cole
Dart Kitten	Dart Aircraft Ltd.
D.H. Dragonfly	V. Bellamy
D.H. Leopard Moth	F. T. Bingham
Deperdussin Monoplane	Shuttleworth Collection, Warden Aviation Co.

Type	*Owner*
Fairchild Argus	Women's Junior Air Corps
Fairchild 24 W-41A Argus	Mr. Davies
Focke-Achgelis Helicopter Kite	College of Aeronautics
G.A.L. Cygnet	L. V. D. Scorah
Hawker Tomtit	Hawker Aircraft Ltd.
Heath Parasol	Ultra Light Aircraft Association
Hoppi-Copter	Hoppi-Copters Ltd.
Messerschmitt Me. 163	College of Aeronautics
Miles Hawk Trainer 3	Redhill Flying Club
Miles M.28 Mercury	J. Milli
Miles M.7A Nighthawk	R. Crewdson
Miles Whitney Straight	Lord Calthorpe
Mosscraft	W. H. Moss
D.H. Moth Minor	G. H. Forsaith
Percival Prince	Percival Aircraft Ltd.
Piper J.4 Cub Coupe	W. Smyth
Tipsy "B"	H. G. Davies
Tipsy	Royal Naval Flying Club

The following is a description of the scale-model aircraft on display.

MEDIUM AND HEAVY BOMBERS

Date	*Type*	*Engine*
1915	de Havilland 3 (Pusher)	Two 120 h.p. Beardmore
1916	Blackburn Kangaroo	Two 250 h.p. Rolls-Royce Falcon
1916	Fairey F.2 (Folding Wing)	Two 190 h.p. Rolls-Royce
1916	Handley Page O/400	Two 360 h.p. Rolls-Royce Eagle
1918	Handley Page V/1500	Four 360 h.p. Rolls-Royce Eagle
1919	Vickers Vimy	Two 360 h.p. Rolls-Royce Eagle
1921	Armstrong Whitworth Sinai	Two 486 h.p. Napier Tiger
1924	Vickers Virginia	Two 450 h.p. Napier Lion
1924	Blackburn Cubaroo	1,000 h.p. Napier Cub
1927	Handley Page Hinaidi	Two 460 h.p. Bristol Jupiter
1933	Handley Page Heyford	Two 480 h.p. Rolls-Royce Kestrel
1934	Fairey Hendon	Two 478 h.p. Rolls-Royce Kestrel
1936	Handley Page Harrow	Two 935 h.p. Bristol Pegasus
1939	Armstrong Whitworth Whitley V	Two 990 h.p. Rolls-Royce Merlin
1936	Vickers Wellington	Two 1,560 h.p. Bristol Hercules
1938	Handley Page Hampden	Two 850 h.p. Bristol Pegasus
1940	de Havilland 98 Mosquito	Two 1,250 h.p. Rolls-Royce Merlin
1940	Handley Page Halifax	Four 1,600 h.p. Bristol Hercules
1941	Short Stirling	Four 1,600 h.p. Bristol Hercules
1942	Avro Lancaster III	Four 1,280 h.p. R.R. Merlin
1949	Avro Shackleton	Four Rolls-Royce Griffon
1949	English Electric Canberra	Two Rolls-Royce Avon Jet

FIGHTERS

Date	*Type*	*Engine*
1913	Avro 504	100-130 h.p. Clerget
1914	Sopwith Baby	100-130 h.p. Clerget
1914	Bristol D. Scout	80 h.p. Gnôme or Le Rhône
1915	de Havilland 2 (Pusher)	105 h.p. Mono Gnôme
1915	Sopwith 1½ Strutter	110-130 h.p. Le Rhône or Clerget

Date	*Type*	*Engine*
1915	Vickers Gun Bus	100 h.p. Monosoupape
1916	Bristol Fighter	250 h.p. Rolls-Royce Falcon
1916	Sopwith Triplane	130 h.p. Clerget
1917	Sopwith Camel	110-130 h.p. Le Rhône or Clerget
1918	Westland Weasel	320 h.p. A.B.C. Dragonfly
1923	Handley Page 21 Scout	230 h.p. B.R.2
1923	Fairey Flycatcher	370 h.p. A.S. Jaguar
1925	Armstrong Whitworth Siskin IIIA	385 h.p. A.S. Jaguar
1927	Westland Wizard	490 h.p. Rolls-Royce
1927	Bristol Bulldog	450 h.p. Bristol Jupiter
1927	Blackburn Lincock	250 h.p. A.S. Lynx
1929	Fairey Firefly S/S Mk. II	450 h.p. Rolls-Royce F Type IIs
1931	Hawker Fury I	525 h.p. Rolls-Royce Kestrel
1934	Armstrong Whitworth Scimitar	640 h.p. A.S. Panther
1935	Fairey Fantome	860 h.p. Hispano-Suiza
1936	Gloster Gladiator	825 h.p. Bristol Mercury
1938	Westland Whirlwind	Two 885 h.p. R.R. Peregrine
1939	Boulton Paul Defiant	1,030 h.p. Rolls-Royce Merlin
1939	Fairey Fulmar	1,145 h.p. Rolls-Royce Merlin
1941	Hawker Hurricane IIC	1,185 h.p. Rolls-Royce Merlin
1942	Hawker Typhoon	2,200 h.p. Napier Sabre
1942	Hawker Tempest V	2,400 h.p. Napier Sabre
1942	Westland Welkin I	Two 1,400 h.p. Rolls-Royce Merlin
1942	Fairey Firefly	2,000 h.p. Rolls-Royce Griffon
1943	de Havilland 100 Vampire	D.H. Goblin Jet
1943	Supermarine Spitfire 21	2,375 h.p. Rolls-Royce Griffon
1943	Supermarine Seafire 47	2,375 h.p. Rolls-Royce Griffon
1944	de Havilland 103 Hornet	Two 2,070 h.p. Rolls-Royce Merlin
1944	Gloster Meteor 3	Two 2,000 lb. R.R. Derwent Jet
1945	Supermarine Spiteful	2,400 h.p. Rolls-Royce Griffon
1945	Supermarine Seafang	2,375 h.p. Rolls-Royce Griffon
1946	Hawker Sea Fury XI	2,480 h.p. Bristol Centaurus
1947	Supermarine Attacker	5,000 lb. Rolls-Royce Nene Jet
1947	Hawker Sea Hawk N7/46	5,000 lb. Rolls-Royce Nene Jet

GENERAL PURPOSE, TRAINING, RECONNAISSANCE AND SPECIAL PURPOSE MILITARY AIRCRAFT

(Recce = reconnaissance aeroplane; Army Co-op = Co-operation type)

Date	*Type*	*Engine*
1917	de Havilland 9a (Day Bomber)	400 h.p. Liberty
1917	Westland Wagtail (Recce)	170 h.p. A.B.C. Wasp
1920	Blackburn Dart (Torpedo)	450 h.p. Napier Lion
1922	Blackburn Baffin (Torpedo)	560 h.p. Bristol Pegasus
1922	Handley Page Hanley (Torpedo)	450 h.p. Napier Lion
1924	Armstrong Whitworth Wolf Trainer	350 h.p. A.S. Jaguar
1924	Handley Page Hendon (Torpedo)	450 h.p. Napier Lion
1925	Fairey Fox (Day Bomber)	460 h.p. Fairey Felix
1925	Armstrong Whitworth Atlas (Recce)	385 h.p. A.S. Jaguar
1926	Handley Page Harrow (Torpedo)	470 h.p. Napier Lion
1927	Blackburn Ripon (Day Bomber)	570 h.p. Napier Lion
1927	Fairey IIIF	570 h.p. Napier Lion
1927	Westland Wapiti	550 h.p. Bristol Jupiter
1928	Handley Page Clive (Troop Carrier)	Two 440 h.p. Bristol Jupiter
1929	Vickers Victoria (Troop Carrier)	Two 570 h.p. Napier Lion
1930	Hawker Hart (Day Bomber)	525 h.p. Rolls-Royce Kestrel
1930	Vickers Vildebeest (Torpedo)	605 h.p. Bristol Pegasus

Date	*Type*	*Engine*
1931	Hawker Nimrod	480 h.p. Rolls-Royce Kestrel
1931	Westland Wallace	655 h.p. Bristol Pegasus
1935	Vickers Wellesley	650 h.p. Bristol Pegasus
1935	Fairey Swordfish (Torpedo Recce)	750 h.p. Bristol Pegasus
1935	Avro Anson I	Two 320 h.p. A.S. Cheetah
1935	Westland Lysander (Army Co-op)	890 h.p. Bristol Mercury
1936	Fairey Battle (Day Bomber)	980 h.p. Rolls-Royce Merlin
1937	Airspeed Oxford I	Two 395 h.p. A.S. Cheetah
1938	Fairey Albacore (Recce)	1,065 h.p. Bristol Taurus
1940	Fairey Barracuda (Torpedo)	1,300 h.p. Rolls-Royce Merlin
1945	Fairey Spearfish (Torpedo)	1,640 h.p. Bristol Centaurus
1946	Short Sturgeon (Recce Bomber)	Two 1,660 h.p. R.R. Merlin
1947	Heston A.2/45 (Observation)	240 h.p. D.H. Gipsy Queen
1947	Avro Anson 20 (Nav. Trainer)	Two 425 h.p. A.S. Cheetah
1948	Boulton Paul Balliol T.2 (Trainer)	1,245 h.p. Rolls-Royce Merlin
1949	Gloster Meteor 7 (Trainer)	Two 3,500 lb. R.R. Derwent Jet

SEAPLANES

(F/B = Flying boat; Float = Float seaplane)

Date	*Type*	*Engine*
1917	Fairey Campania (F/B)	230 h.p. Rolls-Royce Mk. I
1917	Hamble Baby (Float)	110 h.p. Clerget
1918	Fairey N.10 Series III (F/B)	260 h.p. Sunbeam
1922	Fairey Pintail Amphibian	450 h.p. Napier
1922	Supermarine Sea Lion (F/B)	450 h.p. Napier Lion
1924	Fairey Fremantle (Float)	650 h.p. Rolls-Royce Condor
1924	Supermarine Southampton (F/B)	Two 470 h.p. Napier Lion
1924	Fairey Atalanta (F/B)	Four 600 h.p. R.R. Condor
1924	Fairey IIId (Float)	450 h.p. Napier Lion
1927	Blackburn Iris (F/B)	Three 650 h.p. R.R. Condor
1929	Supermarine Scapa (F/B)	Two 525 h.p. Rolls-Royce Kestrel
1931	Supermarine S.6B Racer (Float)	2,600 h.p. Rolls-Royce
1932	Fairey Seal (Float)	525 h.p. A.S. Panther
1932	Short Sarafand (F/B)	Six 820 h.p. Rolls-Royce Buzzard
1934	Saro London (F/B)	Two 1,000 h.p. Bristol Pegasus
1936	Short Empire Boat (F/B)	Four 800 h.p. Bristol Pegasus
1936	Supermarine Walrus (Amphibian)	775 h.p. Bristol Pegasus
1937	Fairey Sea Fox (Float)	380 h.p. Napier Rapier
1937	Short Sunderland (F/B)	Four 815 h.p. Bristol Pegasus
1939	Saro Lerwick (F/B)	Two 1,375 h.p. Bristol Hercules
1940	Saro 37 (F/B)	Four 95 h.p. Pobjoy Niagara
1944	Short Shetland (F/B)	Four 2,500 h.p. Bristol Centaurus
1946	Supermarine Seagull (Amphibian)	1,985 h.p. Rolls-Royce Griffon
1946	Short Sandringham (F/B)	Four 785 h.p. Bristol Pegasus 38
1947	Saro A.1 Jet Fighter (F/B)	Two M/V F.2/4 Jet
1948	Short Sealand (Amphibian)	Two 345 h.p. D.H. Gipsy
1949	Short Solent IV (F/B)	Four 1,795 h.p. Bristol Hercules
1951	Saro Princess (F/B)	Ten 3,500 h.p. Bristol Prop. Jet

LIGHT AIRCRAFT AND GLIDERS

Date	*Type*	*Engine*
1920	Short Silver Streak	240 h.p. A.S. Puma
1923	English Electric Wren	3 h.p. A.B.C.
1923	de Havilland 53	25 h.p. Blackburn
1924	Westland Widgeon III	95 h.p. Blackburn Cirrus
1925	de Havilland 60 Moth	65 h.p. Blackburn Cirrus

Date	*Type*	*Engine*
1927	de Havilland 71 Racer	130 h.p. D.H. Gipsy
1929	Handley Page Gugnunc	150 h.p. A.S. Mongrove
1929	Avro Tutor Trainer	215 h.p. A.S. Lynx
1932	Blackburn B.2 Trainer	120 h.p. Blackburn Cirrus
1934	Percival Mew Gull	200 h.p. D.H. Gipsy
1937	de Havilland 94 Moth Minor	90 h.p. D.H. Gipsy
1937	Chilton	44 h.p. Train
1939	Percival Proctor IV	205 h.p. D.H. Gipsy
1940	General Aircraft Hamilcar Glider	———
1944	Auster Mk. 5	125 h.p. Lycoming
1946	de Havilland Chipmunk	140 h.p. D.H. Gipsy
1946	Percival Prentice	250 h.p. D.H. Gipsy
1947	Short Nimbus Glider	———
1948	Slingsby Motor Tutor	37 h.p. J.A.P.
1948	Fairey Junior	25 h.p. Anzani
1949	Slingsby Prefect Sailplane	———
1949	Slingsby T.21 B Glider	———
1949	Slingsby Gull IV Sailplane	———

COMMERCIAL

Date	*Type*	*Engine*
1917	Handley Page O/700 (11 seats)	Two 360 h.p. Rolls-Royce Eagle
1919	Bristol Pullman (12 seats)	Four 410 h.p. Liberty
1920	de Havilland 18 (8 seats)	510 h.p. Napier Lion
1920	Westland Limousine (6 seats)	450 h.p. Napier Lion
1921	de Havilland 29 (10 seats)	510 h.p. Napier Lion
1922	de Havilland 34 (8 seats)	500 h.p. Napier Lion
1923	Handley Page W.8 (12 seats)	Two 450 h.p. Napier Lion
1924	de Havilland 50 (4 seats)	230 h.p. A.S. Puma
1926	Armstrong Whitworth Argosy (20 seats)	Three 385 h.p. A.S. Jaguar
1926	Handley Page W.10 (16 seats)	Two 450 h.p. Napier Lion
1926	de Havilland 66 (14 seats)	Three 450 h.p. Bristol Jupiter
1926	Handley Page Hamlet (6 seats)	Three 120 h.p. Lucifer
1928	de Havilland 61 (6-8 seats)	450 h.p. Bristol Jupiter
1929	Westland Wessex (6 seats)	Three 140 h.p. A.S. Genet
1930	Handley Page Hannibal (18 seats)	Four 550 h.p. Bristol Jupiter
1930	Airspeed Ferry (10 seats)	Three 100-120 h.p. D.H. Gipsy
1931	Armstrong Whitworth Atalanta (17 seats)	Four 340 h.p. A.S. Serval
1933	de Havilland 86 (17 seats)	Four 204 h.p. D.H. Gipsy
1933	Airspeed Courier (6 seats)	240 h.p. A.S. Lynx
1935	de Havilland Dragonfly (5 seats)	Two 260 h.p. D.H. Gipsy
1936	Airspeed Envoy (Royal)	Two 375 h.p. A.S. Cheetah
1937	de Havilland Albatross (22 seats)	Four 525 h.p. D.H. Gipsy
1937	Armstrong Whitworth Ensign (40 seats)	Four 810 h.p. A.S. Tiger
1937	Percival Q.6 (5-7 seats)	Two 205 h.p. D.H. Gipsy
1938	de Havilland Flamingo (12-18 seats)	Two 900 h.p. Bristol Perseus
1942	Avro York (12-24 seats)	Four 1,620 h.p. R.R. Merlin
1946	de Havilland Dove (8 seats)	Two 305 h.p. D.H. Gipsy
1946	Vickers Viking (24-27 seats)	Two 1,690 h.p. Bristol Hercules
1947	Airspeed Ambassador (40 seats)	Two 2,680 h.p. Bristol Centaurus
1947	Handley Page Hermes V (40-74 seats)	Four Bristol Theseus Prop. Jet
1947	Miles Aerovan (8 seats)	Two 155 h.p. Blackburn Cirrus
1948	Percival Prince (8-10 seats)	Two 520 h.p. Alvis Leonides
1948	Miles Merchantman (20 seats)	Four 250 h.p. D.H. Gipsy
1948	Vickers Viscount (40-53 seats)	Four Rolls-Royce Dart Prop. Jet
1948	Miles Marathon (18-22 seats)	Four 345 h.p. D.H. Gipsy
1949	Bristol Brabazon (74 seats)	Eight Bristol Centaurus

Date	*Type*	*Engine*
1949	de Havilland Comet (32-36 seats)	Four D.H. Ghost Jet
1950	Blackburn Universal Freighter	Four 1,950 h.p. Bristol Hercules
1950	Avro Tudor 9	Four Rolls-Royce Nene Jet

EXPERIMENTAL AIRCRAFT

Date	*Type*	*Engine*
1909	Blackburn Monoplane	30-35 h.p. Green
1910	Bristol Box Kite	50 h.p. Gnôme
1910	Havilland I	45 h.p. de Havilland
1911	Handley Page Yellow Peril	50 h.p. Gnôme
1911	Short Triple Twin	Two 50 h.p. Gnôme
1912	Handley Page Military Trials Machine	80 h.p. Gnôme
1913	Handley Page Anzani Biplane	100 h.p. Anzani
1915	de Havilland I	90 h.p. Renault
1920	Handley Page 17	240 h.p. A.S. Puma
1922	Gloster Bamel Racer	450 h.p. Napier Lion
1927	Westland Pterodactyl Monoplane 1B	70 h.p. A.S. Genet
1928	Fairey Long Range Monoplane	570 h.p. Napier Lion
1930	Westland C.O.W. Gun Fighter	485 h.p. Bristol Mercury
1932	Westland Pterodactyl Sesquiplane V	600 h.p. Rolls-Royce Goshawk
1935	Handley Page 47	665 h.p. Bristol Pegasus
1937	Airspeed Queen Wasp Target	375 h.p. A.S. Cheetah
1937	Napier-Heston Racer	2,500 h.p. Napier Sabre
1941	Gloster Whittle E.28/49	860 lb. B.T.H. Whittle W.1
1945	Handley Page Manx	Two 130 h.p. D.H. Gipsy
1945	Miles Libellula	143 h.p. D.H. Gipsy
1946	Miles M.52 Pilotless Aircraft	W.2/700+No. 4 Augmentor
1947	Armstrong Whitworth 52	Two 5,000 lb. R.R. Nene Jet
1948	Fairy Stooge (Missile)	Four 3 in. A.A. Booster Rockets
1948	de Havilland 108	D.H. Goblin Jet
1948	Bristol 173 Helicopter	550 h.p. Alvis Leonides
1949	Hawker P.1052	5,000 lb. Rolls-Royce Nene Jet
1949	Vickers Nene Viking	Two 5,000 lb. R.R. Nene Jet
1949	Cierva Skeeter Helicopter	145 h.p. D.H. Gipsy
1949	Westland Wyvern	3,500 h.p. Rolls-Royce Eagle
1950	Cierva Air Horse	Two 1,285 h.p. R.R. Merlin

The Council wish to thank sincerely all those pilots, private owners, aircraft firms, flying clubs and associations, ground crews and others who helped so willingly with the display of all aircraft both in the air and on the ground—and made possible the excellent flying programme and static Display. They are particularly grateful to those pilots and aircraft firms from Belgium, France and the Netherlands who brought their aircraft, and to the French Minister for Air who permitted the Nord Stampe Exhibition Squadron to be present and the French Air Attaché and Assistant Air Attaché in London who gave so much assistance in arranging for the French aircraft to attend the Garden Party.

The Council also wish to thank Dr. A. Buchanan Barbour, Chief Medical Officer, British European Airways Corporation, who was in attendance as Honorary Medical Officer during the afternoon.

The work of the Royal Air Force, Cardington, in connection with the Balloon was deeply appreciated, as was the assistance given by Royal Air Force Stations in accommodating visiting aircraft and pilots from abroad.

In addition the Council wish to thank the Berkshire Constabulary, the Royal Automobile Association and the St. John Ambulance and Nursing Brigade (Berkshire Branch) for their services and help, Pyrene Fire Appliances Ltd., Tannoy Ltd. and all those who so readily contributed to the success of the 1950 Garden Party.

REVIEWS

DEVELOPMENT OF AIRCRAFT ENGINES AND AVIATION FUELS. Robert Schlaifer and S. D. Heron. Division of Research, Harvard Business School. 1950. 764 pp. Appendix. Index. $5.75 net.

It is not surprising that with the advent of the gas turbine in the aeronautical field there has been a spate of published work never approached in the hey-day of the piston type aero-engine. This is not to say that there is not still room for another book on the piston engine and we are fortunate in having the present one from authors who are undoubted experts in their own fields—Professor Schlaifer, a physicist and historian of the Harvard Business School and Mr. Heron, veteran of 36 years' experience of engine development and fuel technology.

This unique contribution to aviation literature comprises two research studies sponsored by the Harvard Business School and financed by its Aviation Research Fund contributed by aircraft manufacturing companies. To this enterprise Mr. Heron generously contributed his time and efforts.

We have then this most unusual book presenting in two major sections, the Development of Aircraft Engines and the Development of Fuels. These sections together with a table of contents, two technical appendices and three indices occupy some 764 pages. In addition a wealth of footnotes augment the text.

Part I of the First Section occupies five chapters which deal with the attitude of government to the control of research and development and trace the policies pursued, rightly or wrongly, by the British and United States Governments. Financial control and its effects on the industry and its markets are dealt with and the author gives his conclusions at the end of each chapter.

Part II contains the evidence previously discussed in Part I and presents the high-lights of historical development of air- and liquid-cooled engines over 35 years and concludes with the gas turbine developments relating to the British, American and German efforts in this direction. Technical Appendix A is a valuable account of the dispute over engine cooling in the U.S.A. in the period between the two World Wars.

Section Two by S. D. Heron is also a masterpiece of technical writing, set down from memory and reinforced by later technical discussion with his colleagues engaged on the engine and fuel developments described. Here is the whole important story of aviation fuel development with all the whys and wherefores. Technical Appendix B, occupying only some 12 pages, should be read by every student of fuel technology.

Justice cannot be done to this monumental work in so brief a review. It commands attention—nothing like it has ever been written before in aviation history.

The price of the book in Britain puts it beyond the reach of ownership by many who ought in their own interests to possess and study it. It is however a sound investment and should be on the shelves of every technical library worthy of the name. The actual production of the book by the Andover Press Ltd., Massachusetts is excellent.—N.S.M.

STRENGTH OF MATERIALS. Bevis Brunel Low. Longmans, Green and Co. 1949. 231 pp. 260 illustrations. 254 exercises. 12s. 6d. net.

This is a text book that aims at concentrating on the simpler parts of the subject for the benefit of beginners. Nevertheless it covers much of the basic work required by the engineering institutions and so provides a useful introduction to the whole subject.

After a first chapter on the ideas of stress and strain, the torsion of circular section shafts and the properties of close-coiled springs are discussed. There follow several chapters on the simple theory of bending, concluding with one on leaf

springs. Then come two chapters on riveted and welded joints, and three on principal stresses and strains, and strain energy. The book concludes with three chapters on struts, on theories of elastic failure, and on thick cylinders.

This little book achieves its aim not only by its choice of subjects but by its inexpensiveness. So many modern text books in this field are not only too comprehensive for elementary studies but are priced beyond the means of many students. This is a matter for congratulation of both author and publishers. Another welcome feature of the book is the large group of examples provided at the end of each chapter.

A few unusual features call for comment. In dealing with springs, a short note is included on the effect of curvature on the stresses in the spring wire when its diameter is not very small compared with the coil diameter. In a book of this sort the explanation of such an effect tends necessarily to be inadequate, and the student is left with little more than an empirical correction formula; does this justify the inclusion of the note? In the chapter on beam deflections, the introduction of Macaulay's method, and of the imaginary load method, is refreshing in an introductory text book, but one wonders whether the unmentioned limitations of these methods, which are stated here only in their simplest forms, will not later prove stumbling blocks to the beginner. The reviewer could wish that the chapter on struts were equally refreshing, though here no doubt the author had to choose between adherence to convention and a major change.

Two minor points may be mentioned. In the chapter on rivets, surely a short discussion on the behaviour of metals in relation to the conventional use of limiting average tension, shear and bearing stresses would be preferable to the somewhat bald statement at the top of p. 118 on working stresses? And in the chapter on struts, a purist would like to see the conventional solution for an Euler strut described as indicating neutral equilibrium rather than instability.

The whole book is well printed, and the diagrams have the clarity and style that so many engineers have become accustomed to expect from the author, as from his father before him.—A.G.P.

THREE-DIMENSIONAL ENGINEERING DRAWING. W. E. Walters. Pen-in-Hand, Oxford. 1949. 124 pp. 108 figures. 10s. 6d. net.

This is an interesting book covering some 125 pages in which the author presents the case for three-dimensional engineering drawing.

In this country there are very few instances where information is conveyed from the designer to the craftsman solely by means of isometric drawings, but a great deal of benefit would be derived by supplementing the standard orthographic method by selected three-dimensional views.

There is one branch of engineering where a knowledge of three-dimensional drawing is of particular value, that is in the preparation of repair, maintenance and descriptive manuals. The aircraft industry has developed this type of work to a considerable degree during the past ten years and large staffs are employed in this sphere of activity.

There are a number of patented items of equipment available at the present time, ranging from a selection of special scales, squares and templates to the more elaborate pieces of machinery, with which draughtsmen and illustrators can produce the necessary drawings for handbook use; this book, however, will help those who are not in possession of this equipment.

The volume consists of twelve chapters and an appendix. Chapter I covers—very briefly—the conversion of lines and angles together with the conversion of circular lines.

Chapter II deals with the conceptions of rotation, tilt and foreshortening; this is followed in Chapter III by the elements of straight line solid geometry and applications of three-dimensional projection.

Chapter IV is devoted to practical examples applied to plastic mouldings and a glass container.

Chapter V deals with standard curvilinear work and is mainly concerned with the construction of ellipses, while Chapter VI contains examples of curved outline solid geometrical work and a few notes on shading.

The practical application of curvilinear work is contained in Chapter VII and a number of examples are shown of three-dimensional drawings prepared from standard working drawings. Oblique curvilinear work and rotation of three-dimensional views are dealt with in Chapters VIII and IX respectively and Chapter X contains practical examples of axial work.

Chapter XI is devoted to examples of interpenetration, with elliptical sections of cylinders and cones being described at some length.

The final chapter is devoted to somewhat sketchy covering of work on exploded views. The volume concludes with an appendix which covers some 20 different methods of constructing the ellipse—surely a record for any volume on engineering drawing.

The book is very well produced, the illustrations being clear and suited to the text. It is not a book for the beginner in the accepted sense of the term, and the reader should be acquainted with the elements of standard projection before embarking on the study of this work.—E.J.M.

RUBBER IN AIRCRAFT. T. L. Garner and J. F. Powell. British Rubber Development Board. 1950. 72 pp. 19 figures.

This booklet—as explained in its final chapter—makes an attempt to show not only the multitudinous ways in which rubber is used in aircraft but also to indicate how the versatility of rubber makes it an essential material of construction. An attempt to cover such a broad field within the limits of an easily readable publication of this sort necessarily restricts discussion of the more technical aspects of the subject matter. Hence, the seven chapters (out of ten) devoted to a survey of the uses of the various types of rubber in aircraft will be of interest primarily perhaps to the younger members of the aircraft engineering industry—by broadening their knowledge of the possibilities of using rubber, together with some of its technology.

Some of the more fundamental characteristics of rubber are described in the opening chapter and a brief account of rubber processing is given in Chapter II. The summing up—in the final chapter—makes a number of useful comments and the suggestion of closer collaboration between the designer and rubber technologist will be supported by all concerned.

The booklet—brief as it is—is welcomed as an effort to promote wider knowledge of rubber technology, particularly as the performance requirements of rubber in aircraft are becoming increasingly severe. The several references to low temperature characteristics are of interest in this connection, but, no doubt, many will disagree with the statement (on p. 43) having reference to the tendency to revert to castor base fluids in order to take advantage of the better freezing resistance of natural rubber.

The careful reader will wonder why, in view of the reference (on p. 59) to the use of natural rubber as a sealing medium only of the so-called "bladder cell tanks," the photographs on the two following pages are, obviously, of tanks not of the "bladder cell" variety.—W.H.

AN INTRODUCTION TO HEAT TRANSFER. M. Fishenden and O. A. Saunders. Oxford (Clarendon Press). 1950. 205 pp. Index. Diagrams. 15s. net.

This entirely new book, by the authors of a previous and well-established treatise on heat transmission, has been designed to meet two needs: to give the student a clear and concise introduction to the increasingly important subject of heat transfer, and at the same time to present up-to-date information on the subject in ways convenient for practical use in industry. Although these two aims are not always mutually compatible, the authors are to be congratulated on fulfilling both

aims with a considerable measure of success in the modest compass of two hundred pages, and so meeting a long-felt need for just such an introductory volume as this.

The difficulty of simultaneously fulfilling the conflicting aims which the authors have set themselves is most evident in the first chapter, on radiation. Although it is no easy matter to decide, in an engineering book, exactly how far to delve into the physics of radiation, a bare statement that the Stefan-Boltzmann Law is the most important fundamental law of radiation seems an inadequate basis for an understanding of some of the data presented later. A little more fundamental treatment of the derivation of this Law would have been well worth while.

The chapter on conduction rightly concentrates on the graphical and other practical methods of attack for both the steady and unsteady states, with a minimum of mathematical analysis; a tendency that is evident throughout the book.

A subject which few students grasp at a first encounter, that of dimensional analysis, is dealt with in an excellent chapter serving as an introduction to convection transfer. This is followed by a short chapter on the relation between heat transfer and fluid friction. The reader is referred elsewhere for the more formal treatment of the subject in terms of turbulent motion theory.

The remainder of the book, rather more than half, is devoted to a presentation of data on natural and forced convection, and on heat transfer during condensation and boiling. The chapter on forced convection, the most extensive in the book, includes a study of pressure drop, as well as of heat transfer, in flow across tube banks. While recuperative heat exchanges are thus indirectly considered, there is no chapter on heat exchanges as such, and a notable omission of any reference to regenerative exchangers.

Each chapter contains a number of worked examples, and a useful bibliography of more advanced work on each subject, to which the student may repair to make up for any deficiencies in fundamental treatment resulting from the declared aim of presenting data in ways convenient for practical use.—R.W.H.

CORRESPONDENCE

PRACTICAL TRAINING OF AERONAUTICAL ENGINEERS

Mr. J. M. Hahn, in his paper, "Practical Training of Aeronautical Engineers" (JOURNAL, February 1950), seems to have overlooked a most important department in his chain of contacts for the trainee.

His budding aeronautical engineer spends the time on his Course in learning what goes on in the Shops. He comes to know the problems which confront the Shop staffs so that when he is given the job of designing some part or assembly, he will be able to appreciate the manufacturing difficulties involved.

But this is only half the story. As Mr. Hahn says "The primary function of an aircraft firm is not just to make aeroplanes, but . . . to sell them . . . " This naturally implies that someone is going to use them. It seems logical, therefore, to expect that the aeronautical engineer will need to know something of the problems with which the user is faced.

I would suggest that after the Shop time has been completed, the trainee ought to spend some long time in the Service Department as a Service engineer, working outside the factory with an operator using the firm's products. Only in this way can he see the sort of problems for which he, in time, will be required to cater.

Were all young aeronautical engineers given a period in the Service Department, in time there would arise a race of designers with a background of Service experience who could design aircraft which would be the delight of production engineers and operators alike.

P. R. Mossman, *Associate Fellow.*

MR. HAHN'S REPLY

Mr. Mossman has mentioned an important department. If it was not mentioned in my paper it was because in such a short account, I had to confine myself—as I said at the end of the paper—to "only one aspect of the serious deficiencies in all-round experience which handicap many technicians today."

Once the urgent and pressing need for practical works training has been met, there are several other important sections of the industrial organisation in which it might be considered necessary for a young technician to acquire experience if he is to receive the sound and thorough training which will help him to develop into a professional engineer, for example, the Service Department, the Production Planning Organisation, the Cost Office and the Contracts Department. Unfortunately, life is short, and the time which it is considered justifiable to spend in training an engineer is still limited by comparison with other professions (such as the medical and legal professions).

Clearly what is needed is some carefully devised scheme whereby a young technician can work with, or in, a department in such a way that while he is broadening his experience and training, the firm can at the same time receive the benefit of his academic knowledge. For example, a firm which would be unwilling to lose the services of a young stressman for several months while he toured the Service Department, might be perfectly willing for him to spend some time in that section of the Stress Office which deals with the complaints and queries raised by the Service Engineers. In this way a young stressman could learn a great deal of the difficulties and points of view of the Service Department, while continuing to do a useful job in his own department.

J. M. Hahn, *Graduate.*

AN EXPERIMENT IN FLYING TRAINING

I have read with interest Mr. Rattle's description (JOURNAL, May 1950) of his experience while learning to fly *ab initio* by night, and recall that his conclusions were much the same as those arrived at by the R.A.F. subsequent to their trials of this method of training with a limited number of pupils during the war. Unfortunately I cannot recall any accurate details of these trials, but would be pleased to make some enquiries regarding them in the unlikely event that no other member of the Society can contribute some first-hand information.

I believe also that since the war a pupil at one other flying club at least has learned to solo by night before converting to day flying. It would be interesting to know whether this was ever done before the war.

I would question, however, the author's suggestion that the "two stage amber" system of simulating night flying be used for *ab initio* training in circuits and bumps. Although this system is excellent as a means of simulating instrument flying by night, the limited range of vision outside the cockpit due to the blinker effect of the goggles which must be worn (quite apart from their claustrophobic effect and liability to fog) while the pupil is concentrating on his approach and landing make this delicate process very much harder for the tyro. After all, one's first landings are not all that easy, in spite of Sir Isaac Newton's reliable assistance.

D. R. Maguire.

MR. RATTLE'S REPLY

It is interesting to find that the scheme has been applied to a number of pupils, and if in fact the conclusions were the same as those expressed in the paper, then the practicability of the scheme is more fully borne out. As to the doubts expressed on the matter of using the "two stage amber" system for this training method, I must admit that I have no practical experience of the system, but would suggest that only by actual trial could its possibility or otherwise be affirmed.

A. Rattle.

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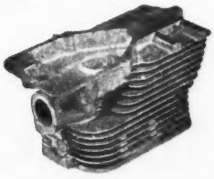

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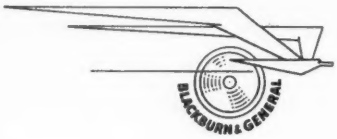

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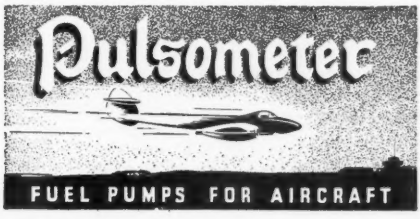

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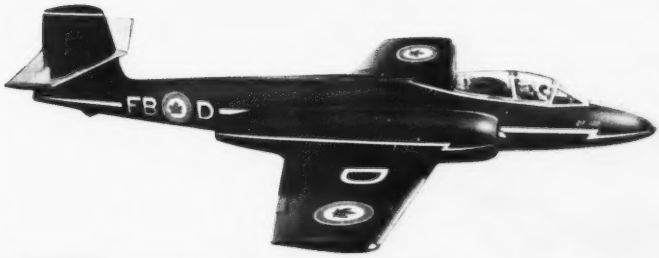

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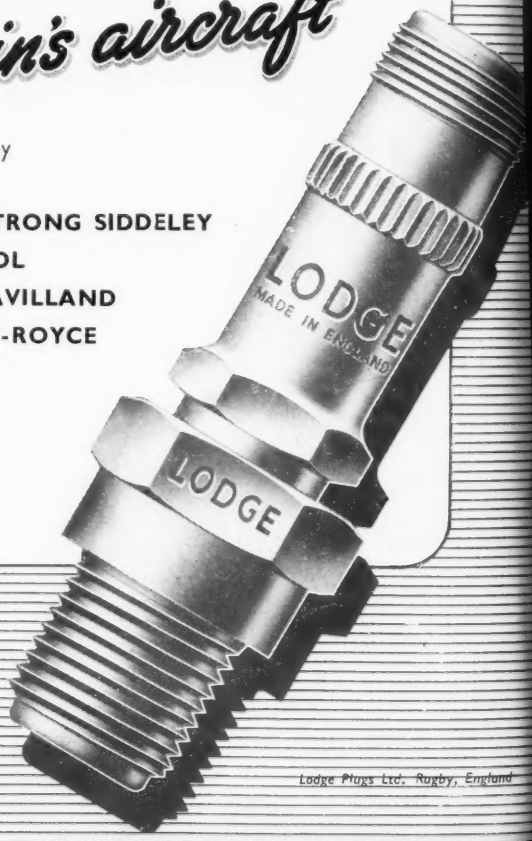

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